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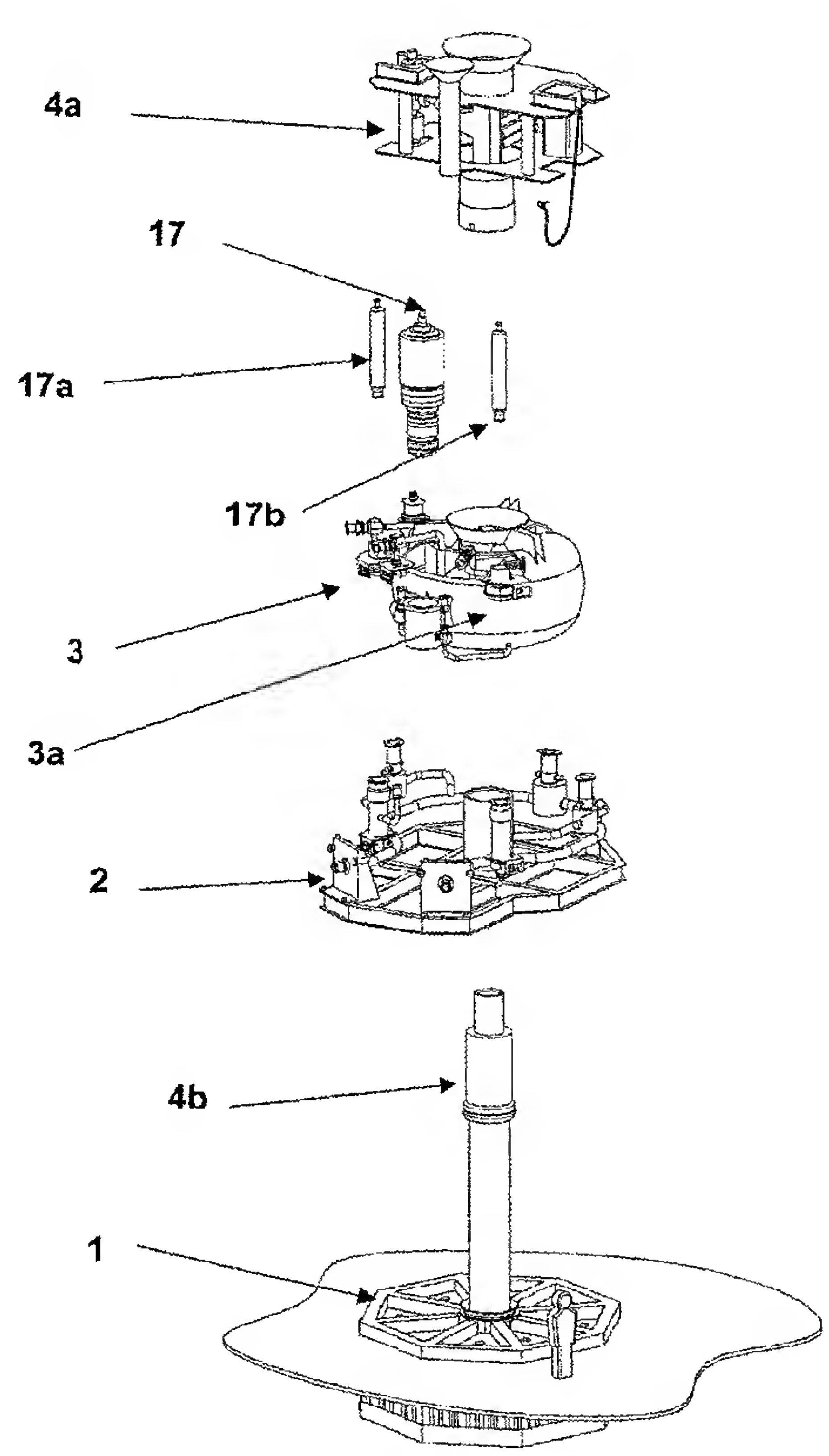
(54) Title: SUBSEA SEPARATION APPARATUS FOR TREATING CRUDE OIL COMPRISING A SEPARATOR MODULE WITH A SEPARATOR TANK




**(57) Abstract:** The invention concerns a subsea separation apparatus for processing crude oil comprising a separator module (3) with a separator tank 3a). The separator tank (3a) surrounds an opening (42) going there through, placed substantially in the geometrical centre of the separator tank (3a). The opening (42) is accessible for other processing equipment for the crude oil. Furthermore the separator tank (3a) may be substantially symmetrically placed on a well head (4b) and the separator module (3) may be substantially concentrically placed on the well head (4b).

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# SUBSEA SEPARATION APPARATUS FOR TREATING CRUDE OIL COMPRISING A SEPARATOR MODULE WITH A SEPARATOR TANK

The present invention concerns a subsea separation apparatus for treating crude oil comprising a separator module with a separator tank for the separation of water, gas, sand and crude oil from fluids flowing from a well. The apparatus or plant is designed to be placed on the seabed adjacent to, or on the well.

During the exploitation of oil and gas offshore, the produced fluids are usually led to a plant, for instance on an offshore platform, for the separation of the various phases of the fluid. These phases includes mainly hydrocarbons, water, and in some cases sand. The separation is usually performed with conventional separation equipment, such as hydrocyclones and sedimentation tanks.

However the are disadvantages connected to placing such separation equipment on offshore platforms. In many cases the platforms imposes limitations to the weight and other design parameters of such plants. Risers, and other equipment to bring the well fluids to the platform and plant, must be dimensioned to lead larger amounts of fluid to the platform, than the fluids that are to be produced. In addition, any reinjection of water into the well will require a lot of additional equipment for leading separated water down into the well. Alternatively, cleaned, but still oil containing water may be dumped directly into the sea, but this is problematic in areas sensitive to pollution.

It has therefore been suggested to place the separation plant on the seabed. This reduces the requirement for surface placed plants, and the need to transport fluids to the surface is reduced in the same amount as the water fraction in the fluid.

Such subsea plants are for instance known from Norwegian Patent NO 304388 describing a method and an apparatus for the separation of a hydrocarbon flow on the seabed. The patent describes a subsea plant for the separation of crude oil fractions. The solution primarily concerns an arrangement and a method for sand processing, and appears limited to the separation of sand in produced water. The processing of sand takes place in the arrangement after pressurization. The sand is taken out downstream in relation to the separator in water with lower pressure. A water injection pump is used to increase the

pressure to a pressure just over the pressure in the separator tank to force the sand to flow into the oil and gas export line. The disadvantages of this, is that the pump must circulate sand containing water, which involves a considerable risk for increased wear with correspondingly high maintenance frequency. This is very cost intensive.

The handling of sand production is a common problem for underwater separation plants. Norwegian patent NO B1 172555 describes an underwater station for the handling and transport of a well flow. The underwater station is placed on the seabed and is intended for the separation of crude oil fractions in the same way as in the solution of the applicant. It is described that a multi phase flow is transformed to 2 phases; a gas phase and a liquid phase, such that the flow as a whole can be moved by means of a single phase pump and a gas compressor. The separation is hence primarily motivated from the transporting needs, meaning that a known single phase compression technology for the pressurization and allows thereby the transfer of the well flow over greater distances than in the case of pressure drop driven transport. What appears described, is mounting the pump directly under the separator and the compressor directly over the separator, in a vertical assembly. The solution of the applicant includes a 3 phase separation where gas, oil and water are treated with the purpose of removing the water fraction.

Norwegian Patent NO B1 309587 shows an apparatus for the separation of an oil/liquid phase from a gas phase in a well head fluid. The patent describes an arrangement for centrifugal separation that either can be placed at the surface or as a part of a subsea plant, for 2-phase separation of crude oil or wet gas.

The apparatus is intended to inflict gravitational forces on the well fluid beyond normal gravitation (g), with the purpose of being able to part the liquid phase from the gas phase quickly, that is 2-phase separation.

The solution of the applicant involves a gravitational separation where the separation is driven with approximately one time the gravitation, 1xg, with the purpose of splitting or dividing crude oil in 3 phases.

Accordingly, the present invention concerns a subsea separation apparatus with a separator tank according to claim 1.

The separation apparatus or the separation plant with a separator tank according to the invention is designed for the separation of water, gas, sand and crude oil from fluids flowing from a well. The separator tank and separator plant is furthermore intended for being placed on the seabed, preferably directly on a well head used as a water injection well, with supply flow of well fluid from a neighbouring production well or a collection of such wells. Alternatively, the well head that the separation plant is placed over, may be a production well or may include production tubing both for production and water injection, a so called "multiple tubing completion".

The pressure equipment is preferably placed upstream in relation to the nodes where the well fluid is merged, and downstream closed to the production well. The purpose of this arrangement is to exploit the heat of the crude oil to, with a temperature as high as possible, ensure the best possible conditions for the separation of water from the crude oil. The equipment may be placed on existing well heads and can easily be connected or disconnected as a module.

The separator tank of the plant is designed substantially concentric about the well head with necessary components or modules placed around it, above it or below, such that the center of gravity of the plant is placed substantially directly above or concentrically around the well head. The separator tank has an opening hole extending there through, essentially in the middle, allowing the well head below to extend through the hole and create a substantially rotationally symmetrical volume. Alternatively, a single phase pump, a multiple phase pump or compressor may be placed in the opening extending through the tank.

Such plants may include a number of elements and modules. Examples of such elements are a permanent guide base (PGB), guide base or flow base, a temporary guide base (TGB) or base frame, a separator module, a well head Christmas tree, a filter unit, connection equipment, oil-in-water censors, connecting frames, permanent bases for guidelines or guide posts, injection

pumps, transformers, choke bridge modules for processed water, “hydrocyclone for sand separation”, Christmas tree for water injection, production Christmas tree, pumps for cast off oil, control mechanisms for Christmas trees, hydrocyclone for oil separation etc..

The elements are preferably built as modules that are placed on the seabed and assembled in a certain order.

These elements or modules are preferably dimensioned according to limitation in connection with installation of the equipment. These limitations are typically the size of the opening of the lower deck or “moonpool” on launching- and maintenance vessels.

The plant enables the separated water to be directly reinjected into the well bore, the latter in the case of a multiple tube completion. Alternatively, separated water may be dumped on the seabed, given a preceding oil separating treatment to reduce the oil content of the separated water. In both cases, transport of water to the surface is avoided. The plant, if it is adapted for reinjection, may comprise a downstream pump with possibly a hydrocyclone (for sand separation) in front. The plant may comprise a hydrocyclone (for oil separation) in the situation where water is dumped at the seabed. In the latter case it may be necessary with an oil-in-water probe or sensor for the control of the oil content.

Direct reinjection at the well head is an environmentally favourable solution. The plant is preferably placed directly on the well head.

The plant is adapted for the connection of pipelines to stab able branch pipes on the plant, and for the connection of a power cable in addition to the placement of a subsea transformer. It can furthermore include connections for a control cable and connections for the placement of control and monitoring equipment.

The plant may include a protective structure of glass reinforced plastic (GRP) or of another suitable material, that makes it possible to trawl over the unit and to protect the plant.

The separator tank according to the invention is preferably torus shaped or in any other way assembled of pressure shell elements with dually curved surfaces. The solution according to the invention involves the separation of crude oil to get rid of the water fraction by directly dumping this fraction to the sea or reinjection to the reservoir by means of an injection well. The torus- or ring shaped separator tank is a gravitational separator tank for the separation of process water. The injection point at the well head Christmas tree is preferably placed immediately adjacent to the center of the separator tank. The sand is washed away ahead of the separator tank by means of a "liquid/gas/sand cyclone" ahead of the inlet of the separation tank. In other words, the invention comprises sand separation from the crude oil phase by means of a "gas/liquid/sand cyclone" at the inlet. The separator tank has no rotating parts, but includes internal guide vanes or plates leading the well flow in a circle around the injection well head, and can be cochleate or reassemble a snail shell. The torus shaped separator tank itself is adapted for 3-phase separation of the well flow. The outer measurements of the tank are reduced to a minimum to make retrieval of the tank to the surface during maintenance operations offshore, easier and more cost effective.

The crude oil preferably flows substantially horizontally through the tank and passes a sector one or several times around the opening in the middle. The central opening extending through the tank is available for process equipment for crude oil. This process equipment may include a water injection Christmas tree, a production Christmas tree or a choke bridge module.

The tank may be adapted with a center tube for guidline less stabbing and assembly of the well head Christmas tree in the opening going there trough. The tank is designed as a pressure wessel and has an upper and a lower shell connectected internally with a thick-walled tube, and externally with a double layer ring structure. The tank may for instance be made of a metal material or a polymer laminate (GRP).

The tank is designed to relatively speaking have a greater pressure resistance towards internal pressure, compared to the pressure resistance towards external

pressure, in a way such that loss of internal pressure not will result in a collapse of the tank, with the effect that retrieval of the installed equipment to the surface is prevented.

The separator tank is internally designed as a labyrinth or a snail shell and is cochleate. The inlet is at the inner side by the center, and the flowing cross section may be progressively increasing such that the velocity component gradually is reduced. At the end of the snail shell, it is placed a standard well wall for collecting the oil fraction pooring over this wall. Separated oil is retrieved behind this wall. A sink for separated water is placed ahead of this wall. Fluid flow concerns are made during the design of the interior, primarily to increase retension time and to reduce turbulence.

The surrounding equipment of the tank, such as pump for separated oil, hydrocyclones, pump for separated water, and in some cases compressors for separated gas, is arranged such that tubular connections are radially configured, and therefore has a minimum length. This is to reduce heat loss. The tank and tubing may be thermally insulated to improve the separation processes and to reduce the probability of ice plug creation.

The tank interior may include fixed level sensors to measure the level of the water/oil transition and oil/gas transition. Because the tank has outer measurements and a mass, accepting simpler retrieval, the level sensors may be integrated as fixed parts, and not as separate retrievable modules, which reduces the need for the use of passages in the pressure shell.

Short description of the enclosed drawings:

Figure 1 is an exploded view of a separation plant with a separator module and a separator tank according to the invention;

Figure 2a shows the separation plant of Figure 1 in a perspective view with cutouts from a first angle;

Figure 2b shows the separation plant of Figure 1 in perspective view with cutouts from a second angle;

Figure 3 shows a perspective view of a separation plant as shown on Figure 1, but where the water injection-tree is removed to clearly show the separator tank, and where this is shown with cutouts;

Figure 4 is a side elevation of a separation plant according to another embodiment of the invention intended for water injection of separated water down into a well, with a corresponding water injection tree;

Figure 5 is a planar view of the invention as shown on Figure 4;

Figure 6 is a side elevation of an exploded view of the invention as shown on Figure 4 and 5;

Figure 7 is an exploded view of a separation plant according to another embodiment of the invention designed for the dumping of separated water on the sea bed, where the water injection tree is substituted by a choke bridge module.

Figure 8 is a side elevation of a separation plant according to a further embodiment of the invention with a hydrocyclone for oil separation, intended for water injection, with a water injection tree;

Figure 9 is a plan view of the separation plant shown on Figure 8;

Figure 10 is an exploded view of the separation plant shown on Figures 8 and 9;

Figure 11 is a partly cut through perspective view of an embodiment of a separator tank according to the invention;

Figure 12 is the separator tank shown on Figure 11 from a different angle;

Figure 13 is a plan view of the separator tank shown on Figures 11 and 12;

Figure 14 is a cross section of the separator tank shown on Figures 11, 12 and 13 from the side. The cross section shows an internal and an external volume;

Figure 15 is a cross section of the separator tank shown on Figures 11-14 in a plan view;

Figure 16 is a cut through perspective view of a separator tank according to another embodiment, where the separator tank includes flow races with approximately constant cross section and prolonged flow path;

Figure 17 shows a cut through perspective view of still another embodiment of the separator tank according to the invention, where cup shells are used. Inserted on the figures are also two views showing the tank in side elevation and plan elevation;

Figure 18 shows a cross section of a separator tank in perspective view according to still another embodiment where the separator tank includes a flow splitter and two parallel chambers;

Figure 19 shows a cross section in perspective view of a separator tank according to still another embodiment with a fixed, built in hydrocyclone for oil separation, mounted by the water outlet;

Figure 20 is a schematic diagram of a separation apparatus with a cross section of a separator tank according to the invention showing how the fluids flow in and out of the tank for water injection to a well;

Figure 21 is a schematic diagram of a separation apparatus with a cross section of a separator tank according to the invention, corresponding to the one shown on Figure 20, additionally showing a fluid gas cyclone, for water injection to a well;

Figure 22 is a schematic diagram of a cross section of a separator tank according to the invention on a well head unit for the production and water injection, where split- or “multiple tubing completion” is used;

Figure 23 is a schematic diagram of a cross section of a separator tank according to the invention where a pump and separator is shown as an assembly, without a well for direct water injection being shown;

Figure 24 is a schematic diagram of a cross section of a separator tank according to the invention where a pump, a compressor and a separator is shown as an assembly, with the purpose of providing a pressure increase in both of the 2-phases (gas and liquid);

Figure 25a is a schematic diagram of a well head unit with a cross section of a separator tank according to the invention adapted for being placed on a production well, where the outlet for oil and outlet for pressurized water is shown; and

Figure 25b is a schematic diagram of a well head unit with a cross section of a separator tank according to the invention adapted for being placed on a production well, where an outlet for water and an outlet for pressurized oil/gas is shown.

The invention will now be described in greater detail with reference to the enclosed drawings, where similar reference numerals refers to similar components.

Figure 1 is an example of a separation plant with a separator module 3 according to the invention, on a well head. The separation plant is shown with a valve tree or water injection tree 4a, on Figure 1 shown to be of a guideline less type, for the injection of separated water with inserts such as; hydrocyclone for gas/liquid and or particle separation 17a, hydrocyclone for oil separation and/or sand mixer 17b, in addition to booster pump 17 for separated water, manifold- and guide frame for any guidelines or pillars called guide base or flow base 2 (PGB), well head

completion 4b and base frame 1 (TGB). The retrievable inserts (not shown on Figure 1) may include sand cyclone modules, connection spools 6, water injection pumps, transformer modules, ROV winch, control parts, choke bridge module, connecting point for umbilical, valve tree for water injection, etc.

From Figure 2a and 2b the parts of Figure 1 are assembled and placed on a well head on the sea bed shown from various angles where the booster pump 17 for separated water and separator tank 3a also is shown.

Figure 3 shows the partly cut through separator tank 3a placed on the connection frame comprises the guide base. The Figure shows the well completion 4b where the water injection tree 4a is removed to provide a better view towards a stabbing skirt or stearing funnel part of the separator tank 3a for the water injection tree 4a.

The Figures 4, 5, 6, 8, 9 and 10 shows several embodiments of separation plants where separated water is reinjected directly into the well (the Figures 4, 5, 6, 8, 9 and 10), or is dumped to the sea bed (Figure 7). The plant includes a gravitational separator tank 3a that is torus or doughnut shaped or in other ways adapted for concentric placement with the well head of the injection well, in the reinjection case. The separator module 3 may be supported by for instance a well completion with "30" "well head" 4b (shown on Figures 6 and 10), and/or as shown, a modified permanent base, called guide base 2 or flow base (PGB). In both cases, this gives a concentric support in relation to the injection well, which is practical to reduce the requirements for foundations, and for reducing the dimensions of the base frame 1 to a structure with a minimal area, for instance modified to include a vertical, sea bed penetrating skirt.

For reinjection (shown on Figure 6) is a related water injection-tree 4a placed as a coupling with connection directly between the outlet for separated water from the separator tank 3a and the well head itself. To reduce the vertical high of the assembly, the connection spool on the valve tree may be placed higher than the well head coupling. The injection tree 4a may include four, three or no (guidelineless) stearing posts or guiding. In the event if stearing posts are used,

these are placed in a favourable way in relation to the separator tank 3a lying below. The direct connection allows separated water to flow from the separator tank 3a and directly to the valve tree. Solutions suggested by others frequently involve a considerable distance between the tank and the injection tree. This increases the risk that the separated water, that often contains residue of hydrocarbon, is cooled such that hydrate ice plugs are created in the tube. The solution according to the invention reduces this risk considerably. Furthermore the solution results in a reduced number of valves and connections and accordingly the number of seals and potential leaks.

The plant has preferably standardized components for both the case with direct reinjection, and the case where process water is dumped at the sea bed. This makes it possible to use exchangeable components for the two different cases. This has many advantages in connection with the equipment costs, fabrication time, production flexibility and reduced stock holding of spare components for the operator. Examples of such components are separator tank 3a, hydrocyclone for particle separation 17a, connection spools 6, and flow base/guide base (PGB) 2 with flow tubes, connection frame and stearing posts, the latter in the case where guidelines are used.

The guide base 2 may be modified to control the flow of separated water in the case where separated water is dumped at the sea bed. The plant may imply that the outlet for separated water from the separator module 3 has a design that both can accept of the type pump/motor insert (in the case of reinjection), or a hydrocyclone for oil separation (in the case dumping at the sea bed). Both inserts may make use of a system with radially acting sealing arrangements.

The shown arrangement implies a “placing of the modules in layers”, where relative reliability considerations are the basis for the placement of the individual components in the function controlled arrangement, that in the invention is shown with a vertical connection or “stack-up”. ROV-operated valves may for instance be placed in the guide base 2 along with piping systems and alternatively a collector tank for sand 5, see the hydrocyclone for particle separation 17a. The separator module 3 that is being supported by the guide base 2 includes remotely

operated valves. Above the separator tank 3, vertical connection spools 6 are used as connection tubular. These connect the tubing system in the guide base 2 with the separator tank 3a. On the inlet side, the connection tubular 6 may include a hydrocyclone for particle separation 17a, as a relatively high degree of mechanical wear results in expected high frequency of replacement. The outlet side for separated water also implies connection spools for the connection tubular 6, and reference is made to the water injection-tree 4a and the choke bridge module 18, used in the cases with direct reinjection and dumping at the sea bed respectively. The water injection-tree 4a can be said to have a double function; as a connecting element, corresponding connection tubular 6, and as a valve block for well head valves necessary for the injection function. The choke bridge module 18 is thought to contain oil-in-water sensing instruments 22 and control/choke valves, where one, some or all of these components are either separately retrievable or fixedly mounted in the module.

A very important feature, is to prevent hydrate creation in tubes that contains water that continuously or periodically contains hydrocarbons. This is called "cold spots" that are cold places in the tubular system that may cause hydrate creation, with the relating hazard of clogged tubes. By leading tubes through the separator tank 3, as shown in Figures 5 and 9, the heat from the crude oil, stored internally in the tank, may be used to prevent or retard hydrate creation.

In connection with Figures 4 and 5 and 8 and 9, it is shown protective structures 12 with built in opportunity for access to the plant. The arrangement that principally involves a fixed angular distribution between pull-in points and access corridors for ROV, is shown with a 120° distribution with three pull-in points; one for a pipeline, one for a power cable for transformer, and one for power connections towards a pump inserts respectively. This provides for a design with a more effective protective structure, in that a rotationally symmetrical embodiment with three repelling corners may be used. All of, or parts of, the protective structure may include pivotal elements, or lids, of fibre glas reinforced plastic (GRP).

Figure 4 is a side elevation of a separation plant according to the invention placed on a well head on a sea bed, intended for water injection of separated water back into the well. From the figure, it is shown a base frame 1 where a guide base 2, with or without guidelines and guide posts is placed on the base frame 1. The guide base 2 may also include a connecting frame or flowline termination 16, tubular system with appurtenant valves and parts of the inlets- and outlet cyclones, for instance sand trap 5, on the inlet side. Furthermore it is shown a Christmas tree for water injection 4a, a levelling mechanism 14, a hydrocyclone for sand separation 17a with sand trap 5, and a connecting frame, in addition to a transformer module 10 and a control pod 9 for the separator.

Figure 5 is a plan view of the separation plant on Figure 4, showing the placement of the component in relation to each other on the base frame 1. The Figure also shows a power and control jumper 12 and a termination 13 for the power and control jumper. Furthermore it is shown a connection tubular (rigid spool) 6, an injection pump insert 17, an oil-in-water sensor 8, the control pod 9 for the separator module 3, and the transformer module 10. The connection tubular 6 may include an oil-in-water sensor 8. A protective structure 15 is shown with a dashed line.

Figure 6 is an exploded view of the embodiment shown on the Figures 4 and 5. A base frame (TGB) 1 supports a modified permanent guide base 2 for the tube and valve arrangement, including guide posts for the condition where guidelines are used, in addition to parts of the hydrocyclone 17a with the sand trap 5, and a hinged connection frame. A VE-MEC-flowline termination 16 is shown connected to the guide base 2. Furthermore the Figure shows how a hydrocyclone for sand separation 17a, connection tubular 6, the injection pump insert 17, the control pod 9 for the separator, the water injection-tree for processed water 4a, the oil-in-water sensor 8 and the transformer module 10, all are assembled for the separator plant of the invention. The protective structure 15 is shown with a dashed line. This protective structure 15 may be made of fibre glas reinforced plastic (GRP).

Figure 7 is an exploded view of a plant with many similar features to the one shown on Figure 6, but shows an embodiment of the plant adapted for the dumping of separated water at the sea bed. The Figures shows that this separator plant also includes a hydrocyclone for sand separation (inlet) 17a, a control pod 9, a hydrocyclone for oil separation (outlet) with a turbine driven pump 17b, for separated oil from separated water, an outlet for separated water directly to the sea after the oil-in-water sensor 8, a choke bridge module 18 and a connection 19 for an umbilical cord. A separately retrievable choke valve or choke insert 20 is also shown. The separator module 3 may furthermore support its own vertically retrievable modules. In the case of direct injection and dumping at the sea bed, the injection pump insert 17, and the hydrocyclone for oil separation 17b placed by the outlet for separated water and from the separator tank, respectively.

Figures 8, 9 and 10 shows an arrangement for direct reinjection where also a hydrocyclone for oil separation of water out from the separator tank is placed at the outlet. There are possible uses of the invention where the composition of the produced fluid in relation to the volume of the separator tank 3, which decides the time of residence in the tank, means that maximum oil content, typically 300-1000 ppm, not can be expected after the gravitational separation in the tank. It is therefore desirable to perform a pre-treatment, before the injection pump-insert or the booster pump 17 for separated water, to remove the oil in the separated water. This is done by using a hydrocyclone for oil separation 17b, as shown on the Figures. The hydrocyclones 17a and 17b, may be separately retrievable in that they are placed in the same type of fixture as the water injection pump insert 17.

Figures 8 and 9 are plan and side elevations of a separation plant corresponding to the one shown on the Figures 4 and 5, but where the separation plant, as mentioned, also includes a hydrocyclone for oil separation 17b on the outlet side. This hydrocyclone may include a water turbine driven pump for refused oil.

Figure 10 is an exploded view of the plant shown Figures 8 and 9, where the hydrocyclone with turbine driven pump 17b for separated oil is clearly shown.

Figures 11 to 15 show the separator tank (shown as 3a on the figures mentioned above) according to one embodiment of the invention. Figure 11 shows that the separator tank includes a center hole or an opening going there through 42 for the well head 4b, placed substantially at the center of the separator tank. The separator tank is substantially torus- or ring shaped and the center hole 42 for the well head is placed substantially at the center of gravity of the tank. On the figures it is shown a gas inlet 37 from the hydrocyclone 17a, a liquid inlet 38 from the same cyclone, an outlet for process water 39, an outlet 40 for oil and a level indicator 41.

Figures 12, 13, 14 and 15 shows the separator tank in further detail. The shown tank is a torus shaped subsea tank for 3-phase separation of the well flow, where the outer measurements of the tank are reduced to a minimum, to make retrieval of the tank during maintenance operations offshore easier and more cost effective.

The tank for tree phase separation of the well flow may have a stabbing skirt placed at the top of the center tube, adapted for guideline less installation of a Christmas tree. This is particularly favourable for installations of arrangements, placed in deep water (>600 m w.d.). The tank is designed as a pressure vessel and may have an upper and a lower shell connected internally with a thick walled tube and externally with a double walled, ring structure. The tank is designed to be relatively stronger for internal pressure, compared to external pressure such that implosion with any loss of internal pressure not shall result in deflection or collapse of the tank, preventing retrieval to the surface.

The tank may include an internal arrangement 44, 45 made as a “labyrinth” or a “snail shell”. The inlet is placed innermost at the center and the cross section of the flow is progressively increasing such that the velocity of the flowing crude oil gradually is reduced. At the end of the “snail shell” a standard well wall 41 is placed. Separated oil goes out behind the well wall and separated water goes out in front, through a sink at the bottom of the tank. It is made flow technical

concerns during the design of the internal arrangement, first of all to maximize the time of residence and to minimize turbulence.

The separator tank has thereto affixed surrounding equipment such as a pump (for separated water), hydrocyclones an compressors (for separated gas). These elements are arranged such that tube connections are oriented with radial orientation, and have thereby the shortest possible length to reduce heat loss. The tank and the tubes are in addition thermally insulated to improve the separation process, in addition to reduce the hazard for the creation of hydrate ice plugs inside the tubes.

The internal arrangement of the separation tank may include permanently installed level sensors to part liquid/gas and liquid/liquid (oil/water). As the tank has external measurements and a mass allowing simple retrieval to the surface, the level sensors may be integrated as permanently installed parts, as opposed to separately retrievable modules. In this way unnecessary use of space and passages such as flange joints is avoided.

Figure 12 shows an example of an internal arrangement 44 in the tank.

Figure 13 shows that the tank is substantially symmetrically about the center hole 42 for the well head.

Figure 14, shows a cross section of the tank seen from the side, and that the tank includes an internal vertical wall 45 parting the tank in two races creating two connected volumes. These are shown as an inner race volume 43 and an outer race volume 46.

Figure 15 is a cross section of the tank seen from the inside where the inner race volume 43 and the outer race volume 46 are clearly shown. Furthermore the figure shows where the inlet for the liquid from the hydrocyclone 38 goes into the inner race volume 43 and where the outlet for the process water 39 is placed in the outer race volume 46 and the placement of the oil collector 41 at the oil outlet 40.

Figure 16 shows an alternative embodiment of a separator tank according to the invention. From the figure it is shown that the tank includes internal deflector plates or guide vanes. The shown tank has a pressure carrying cup shell with an internal arrangement suited to prolong the flow path. The tank is symmetrical about the center hole or the opening 42 for the well head going there through. The inlet 38 for fluid that is to be separated, or crude oil, follows along the dashed line 48 along the inside of the separator tank. A water outlet 39 and oil/gas outlet 40 is also shown.

The shown separator tank is a tank with three horizontal spheres or cup shells. In the shown embodiment, there are internal plates, deflectors that are placed to increase the separation time and to increase the distance between inlet and outlet as much as possible.

Figure 17 shows the described alternative separator tank, with three horizontal spheres creating an internal volume where the separation of crude oil takes place substantially in conditions corresponding to what is normally called a *"horizontal separator"*. The separator consists of cup shell symmetrically placed about the opening 42 that is formed by a cylindrical tube in the center going there through. The cylindrical tube in the center is designed for access to the well head. The inner volume of the separator is substantially established by the use of these cup shells. The separator will typically be exposed for internal and external pressure corresponding to the production pressure of the tube system and approximately full hydrostatic pressure respectively. Cup shell gives clear advantages in terms of wall thickness in the separator tank, in relation to necessary welding technology during fabrication, use of materials, weight and thereby expenses. These properties are a result of that the cup shape mechanically speaking is optimal in relation to the smallest surface in relation to closed volume, and the ability to withstand external pressure loads with a good stability towards dimensional changes. The cylindrical tube has an internal diameter adapted to the outer diameter of a connection for a well head coupling belonging to a water injection-tree.

Figure 18 shows still a further embodiment of a separator tank with parallel separation chambers. From the figure the circulation is shown with the dashed line 48.

The chambers are shown with an internal quantity splitter. Separated crude oil in cup # 2 is divided in two volumes for separation in cup # 1 and # 3 respectively by means of an internal quantity splitter, shown as placed in a Y-configuration in cup # 2.

Figure 19 shows still another embodiment of a separator tank with an outer water outlet integrated in hydrocyclone 51, with an internal inlet 50. From the figure, control valves 53 placed at the inlet of an ejector and at the outlet for separated oil 52 to crude oil 40 with low water content, and outlet for separated water 39 is shown.

This separator tank also comprises internal deflectors, see above, where separated water at the outlet of the flow path, is led through a built in hydrocyclone 16 arranged to reduce oil content in separated water.

Figure 20 shows schematically a separation plant with a separator tank in cross section, to show how the plant is placed around a water injectiontree well head.

Figure 21 shows schematically how a plant with a liquid/gas hydrocyclone at the inlet, is placed around a water injectiontree-well head.

Figure 22 shows schematically an arrangement for the production of crude oil and injection of separated water, in the same well head completion.

The separator tank, as a part of a separator module described above, can find its use where the center position is used to place a pump for separated water, and/or a combination of liquid pump and gas compressor. This gives a very compact assembly of the equipment.

Figure 23 therefore shows schematically a plant without a well head, where the assembly gives a "compact pump and separator unit".

Figure 24 furthermore shows schematically a plant without a well head, where the assembly gives a "compact pump/compressor and separator unit".

Figure 25a is a schematic diagram of a well head unit for production with pressure in the water outlet, adapted for placement on a production well, where the inlet 38, the outlet for oil 40 and the outlet for pressurized water 39 is shown.

Figure 25b is a schematic diagram of a well head unit for the production with pressure in the oil/gas outlet, showing a cross section of a separator tank according to the invention adapted for being placed on a production well, where the inlet 38, the outlet for water 39 and the outlet for pressurized oil/gas 40 is shown.

In this specification it has been described a subsea plant. It may however also been practical to use such a plant at land based installations.

# Patent claims:

1. Subsea separation apparatus for processing crude oil including a separator module (3) with a separator tank (3a), where the apparatus further includes other process equipment for the crude oil,
characterized in that the separator tank (3a) surrounds an opening (42) going there through, placed substantially at the geometrical center of the separator tank (3a), the opening (42) being accessible for the process equipment for the crude oil.

2. Subsea separation apparatus according to claim 1,
characterized in that the separator tank (3a) is placed on a well head (4b);
the separator module (3) is substantially concentrically placed on the well head (4b); and
the separator module (3) is substantially horizontally placed and has a vertical central axis in addition to a center of gravity substantially concentrically placed in relation to the well head (4b).

3. Subsea separation apparatus according to claim 1 or 2,
characterized in that the apparatus furthermore includes:
a base frame (1);
a guide base (2) placed on the base frame (1);
a tubing- and valve system placed on the guide base (2); and
where the separator module (3) is placed on the guide base (2).

4. Subsea separation apparatus according to claim 3,
characterized in that the guide base (2) includes guideline fixtures/guide posts.

5. Subsea separation apparatus according to claim 3,
characterized in that the centering of the process equipment for the crude oil on the separator module (3) is guideline less, in that separator module (3) has mounted thereto a stabbing skirt for guideline less centering.

6. Subsea separation apparatus according to claim 1 or 2, c h a r a c t e r i z e d in that the apparatus is placed by a well bore for returning separated water from the apparatus down into the well bore for returning separated water, and where the well bore for returning separated water is provided with a well head (4b) for separated water; and
the process equipment for the crude oil includes a water injection Christmas tree (4a) placed on top of and through the opening (42) going through the separator module (3) on the well head for the injection of separated water, produced in the separator tank part (3a) of the separator module (3), in the well bore.

7. Subsea separation apparatus according to claim 6, c h a r a c t e r i z e d in that the separator module (3) is provided with an injection pump (17), and connections for hydro cyclones (17a, 17b) for pre-processing at an inlet (17a), including sand separation, and post-processing at an outlet (17b).

8. Subsea separation apparatus according to claim 6, c h a r a c t e r i z e d in that the water injection Christmas tree (4a) is placed as a connection spool element, directly between an outlet for water separated from the separated tank (3a), and the well head (4b);
a flow line connection of the water injection Christmas tree (4a) placed higher than a connection to the well head completion (4b) to reduce the vertical height of the assembly of these components;, and
the separator tank (3a) is in fluid connection with separated water via the direct coupling to the water injection Christmas tree (4a).

9. Subsea separation apparatus according to claim 6, c h a r a c t e r i z e d in that it includes a sand and/or a gas/liquid hydrocyclone (17a), for pre-processing the crude oil before the inlet in the separator module (3) for the reinjection of water separated from the crude oil, and that the separated water is post-processed ahead of the injection pump (17) to remove oil dissolved in the separated water.

10. Subsea separation apparatus according to claim 1 or 2, c h a r a c t e r i z e d in that the apparatus is adapted for dumping separated water from the apparatus in that the process equipment for the crude oil constitutes a choke bridge module (18) placed at the top of and through the opening (42), going through the separator module (3).

11. Subsea separation apparatus for processing crude oil according to claim 10,
c h a r a c t e r i z e d in that it includes a hydrocyclone (17b), for separating oil, filtering and cleaning, placed at the outlet for separated water from the separator module (3), before dumping cleaned water through an oil-in-water censor (8).

12. Subsea separation apparatus according to claim 1 or 2, c h a r a c t e r i z e d in that the apparatus is adapted for being placed on a production well; and
where the process equipment for the crude oil includes a production valve Christmas tree placed on top of and through the opening (42) going through the separator module (3).

13. Subsea separation apparatus according to claim 1 or 2, c h a r a c t e r i z e d in that tubes for the crude oil are led through the separator module (3) in such a way that heat from the crude oil, stored inside the module, is used to prevent or delay the creation of hydrate ice plugs.

14. Subsea separation apparatus according to claim 1 or 2, c h a r a c t e r i z e d in that the separator tank (3a) is a horizontal 3 phase separator tank (3a) based on use of doubly curved pressure shell elements, and where these are rotationally and symmetrically placed and includes a cylindrical tube in the centre for access to a well head, where the tube may include a skirt for guideline less centring and alignment of the well head Christmas tree.

15. Subsea separation apparatus according to claim 1 or 2, c h a r a c t e r i z e d in that the separator tank (3a) of the separator module (3) is pressure carrying and is relatively stronger for internal pressure, that external

pressure and furthermore is shaped such that a potential implosion with potential loss of internal pressure not results in a deflection of the tank that prevents retrieval of the separator tank (3a), or installed equipment to the surface.

16. Subsea separation apparatus according to claim 1 or 2, c h a r a c t e r i z e d in that the separator tank (3a) part of the separator module (3), has internal deflectors placed such that the fluid path between the inlet and the outlet is extended, to maximize the time of residence, and that the deflectors in their design contributes to maximum turbulence during the separation.

17. Subsea separation apparatus according to claim 1 or 2, c h a r a c t e r i z e d in that the separator tank (3a) has an internal arrangement (45) shaped as a "labyrinth" or "snail shell", with an inlet at the inner side at the centre, and where the cross section of the flow is progressively increasing such that the velocity component is gradually reduced, and a standard well wall is placed at the end of the "snail shell", behind which separated oil can be collected, in front of which a sink for separated water is placed.

18. Subsea separation apparatus according to claim 1 or 2, c h a r a c t e r i z e d in that the separator tank (3a) included an internal quantity splitter for separating separated crude oil into two volumes.

19. Subsea separation apparatus according to claim 1 or 2, c h a r a c t e r i z e d in that the separator tank (3a) includes a built in hydrocyclone (51) and that the separator tank (3a) furthermore is shaped such that the hydrocyclone (51) is in fluid connection with an outlet (40) such that the hydrocyclone (51) reduces the oil content of the separated water.

20. Subsea separation apparatus according to claim 1 or 2, c h a r a c t e r i z e d in that it furthermore includes a number of separate retrievable modules for control and measurement instrumentation, such as control modules, level sensors, and censors for the measurement of pressure, temperature and oil content in the separated water.

21. Subsea separation apparatus according to claim 20, characterized in that the other retrieval modules for increasing pressure and/or for- and post-processing with inlet- and outlet of the separator tank respectively, are of a concentric insert type such as: insert water pump, insert hydrocyclone, insert oil pump, insert choke valve, where these makes use of the opening (42) in the middle of the tank (3a).

22. Subsea separation apparatus according to any of the preceding claims, characterized in that the separator tank (3a) is torus shaped.

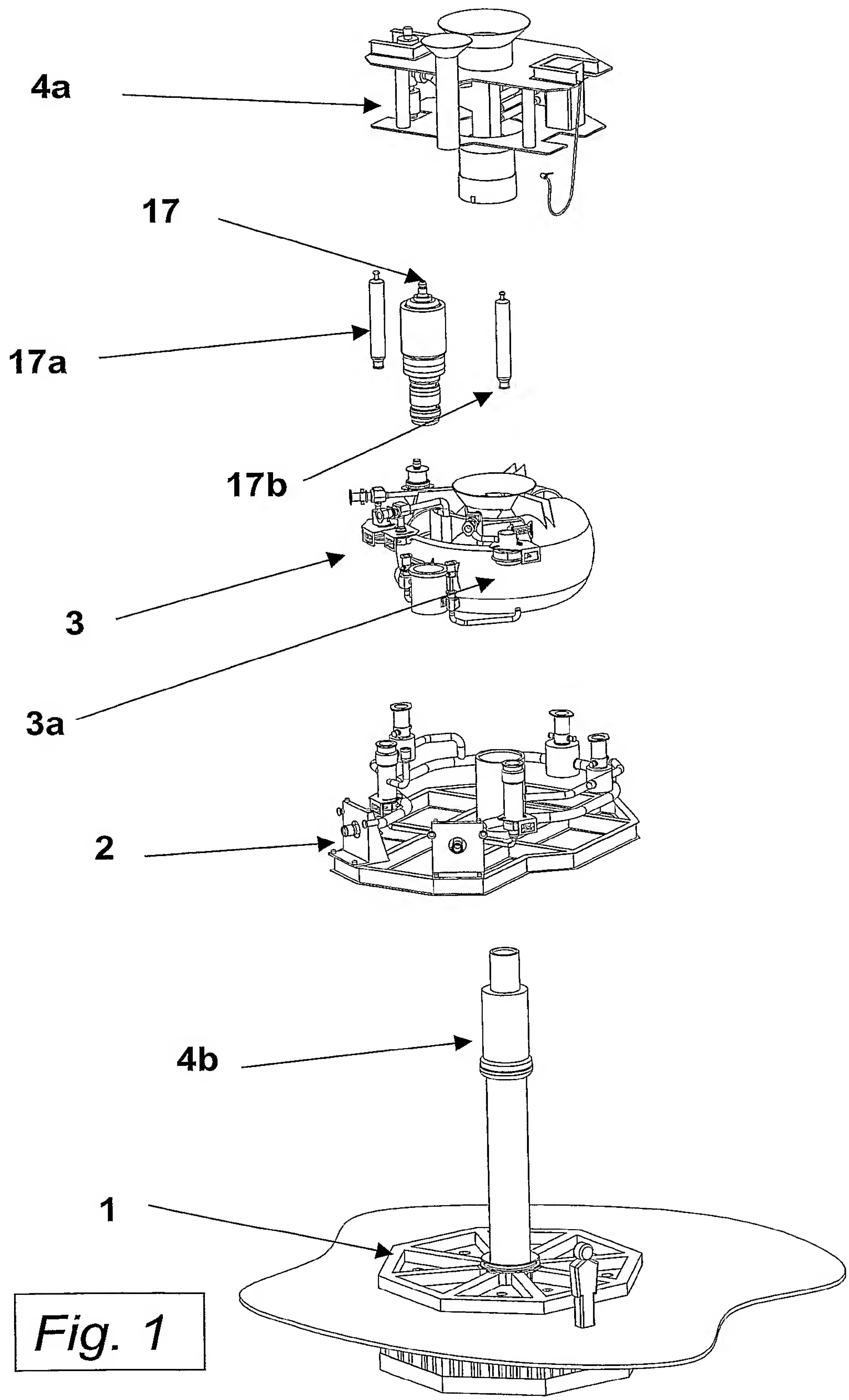



Fig. 1

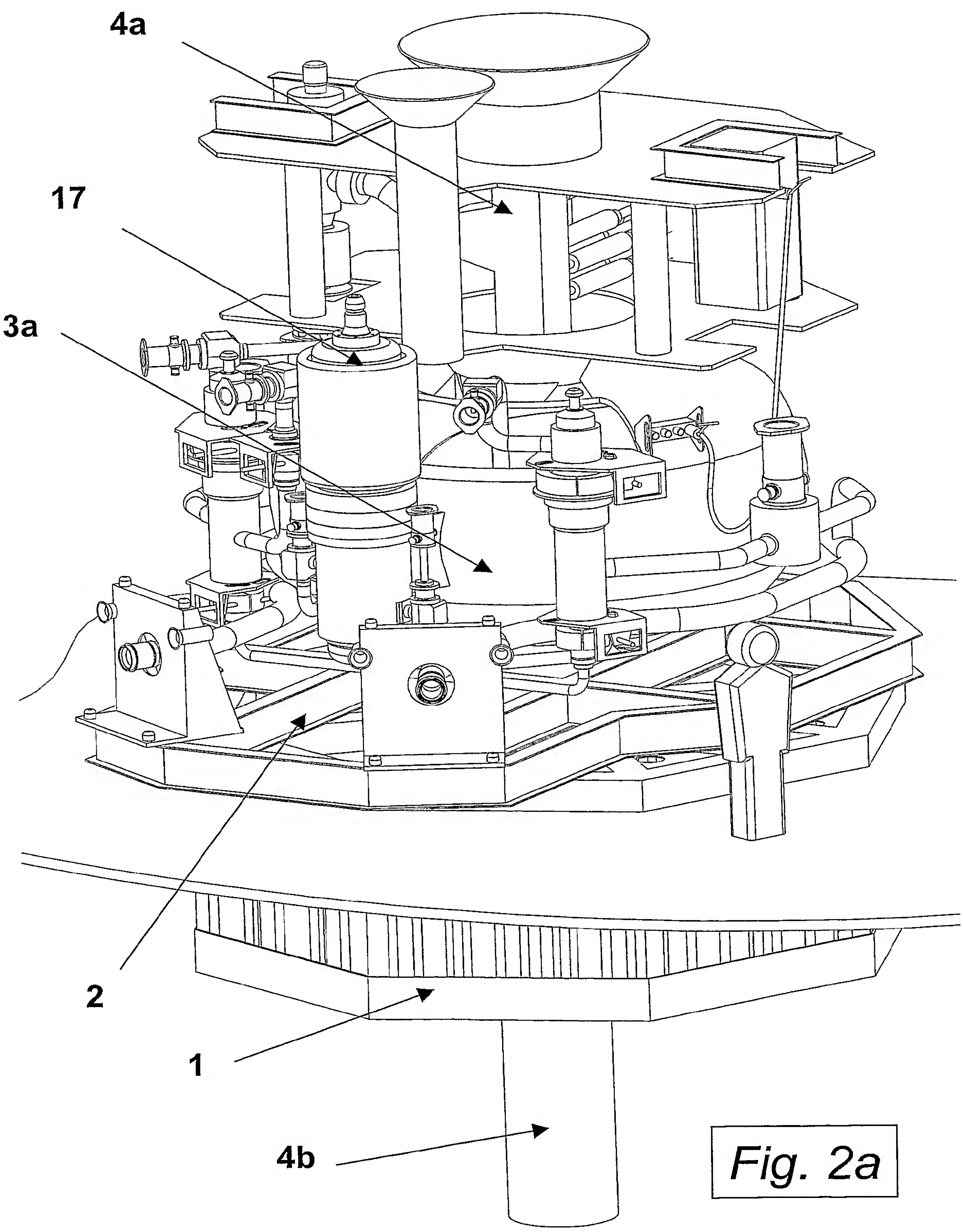



Fig. 2a

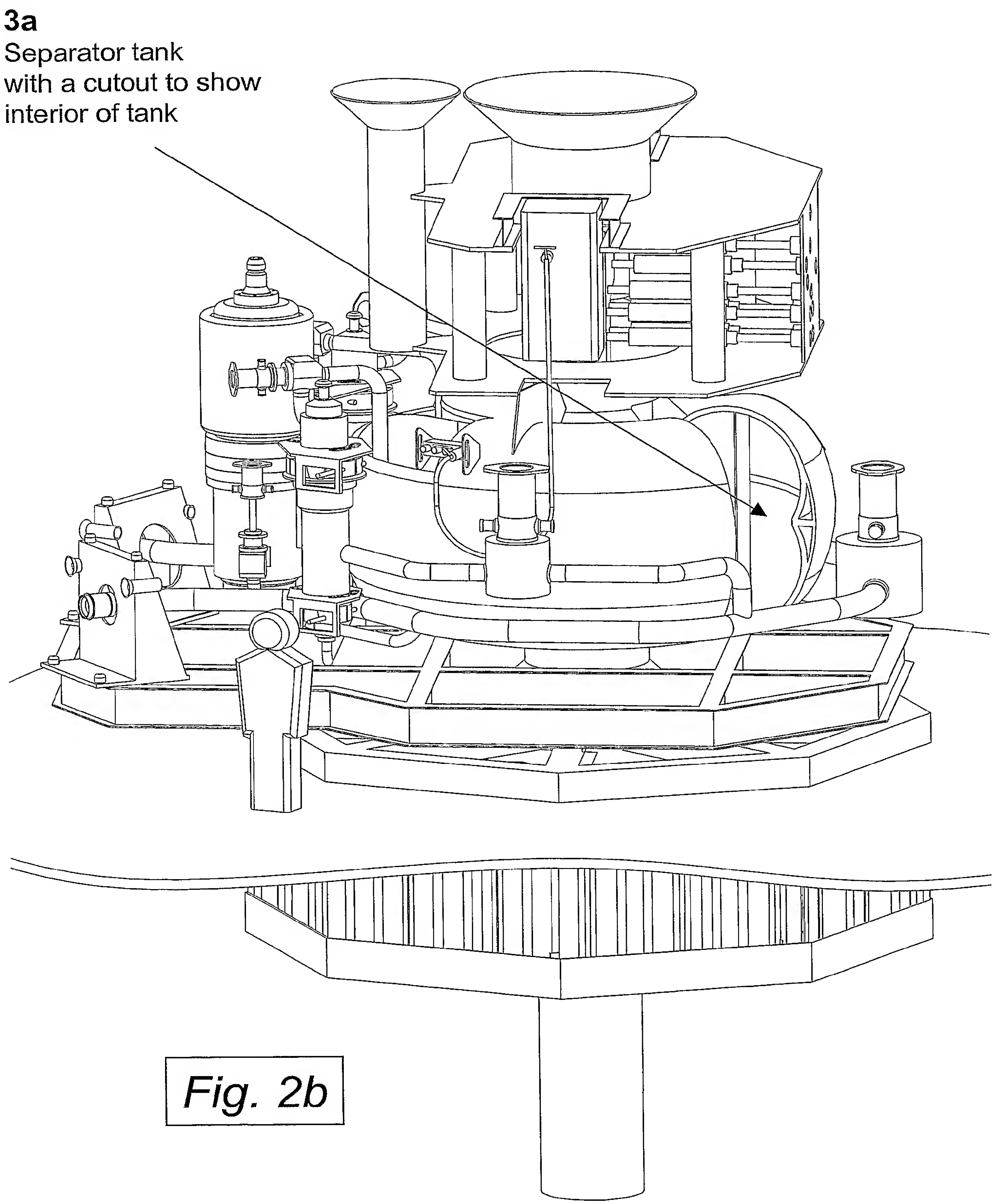



Fig. 2b

Separator tank with a cutout to show interior of tank

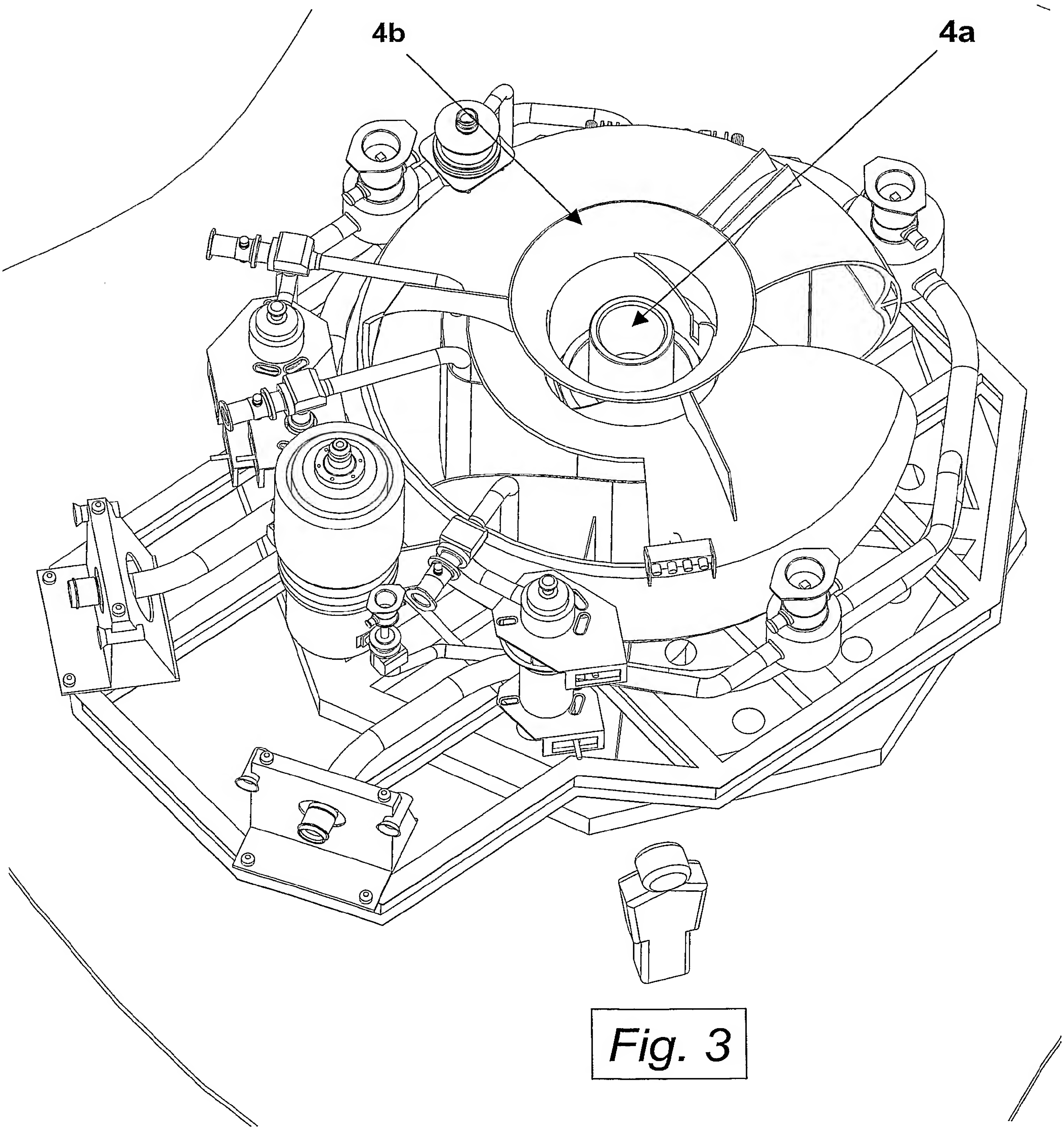



Fig. 3

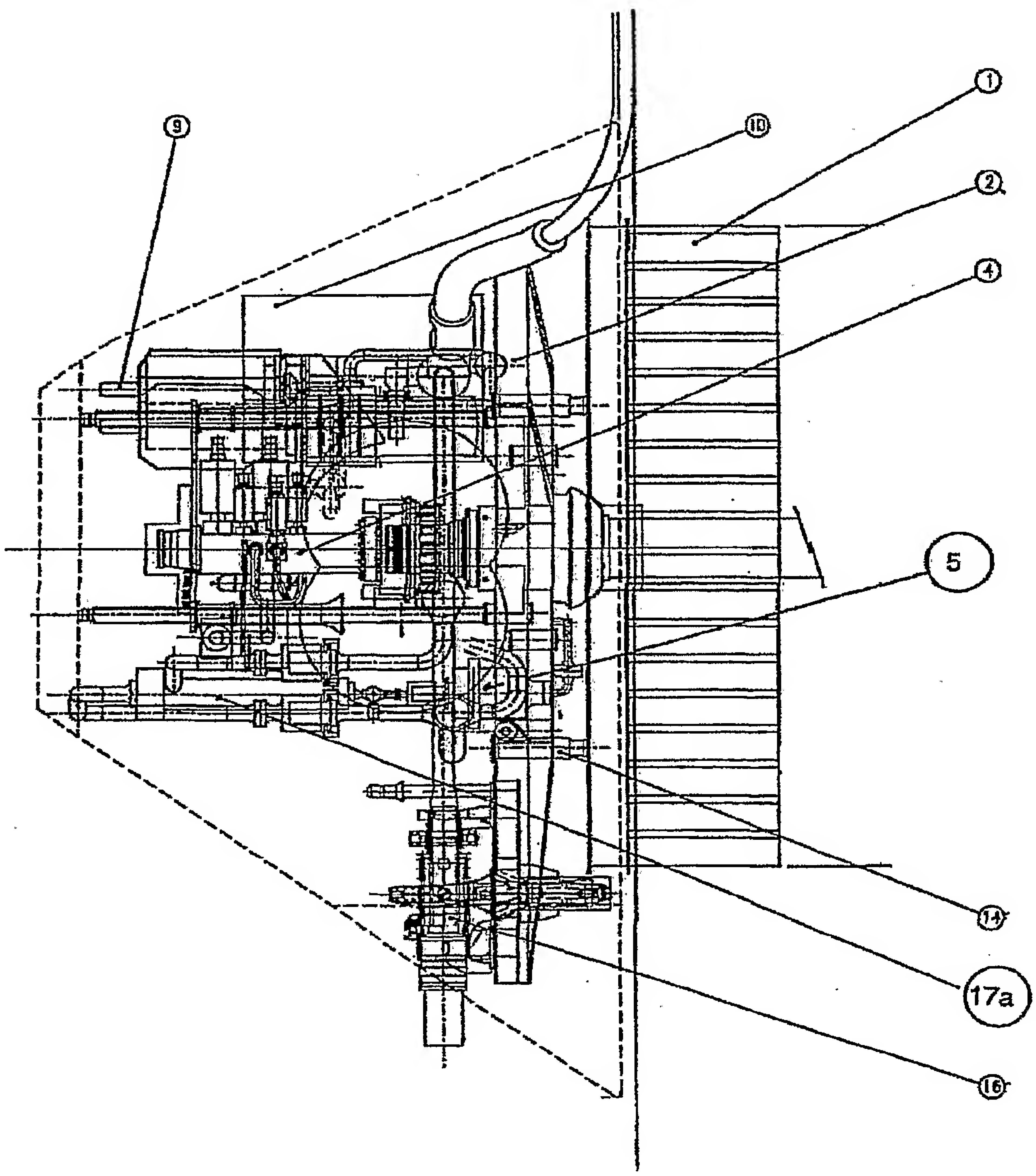



Fig. 4

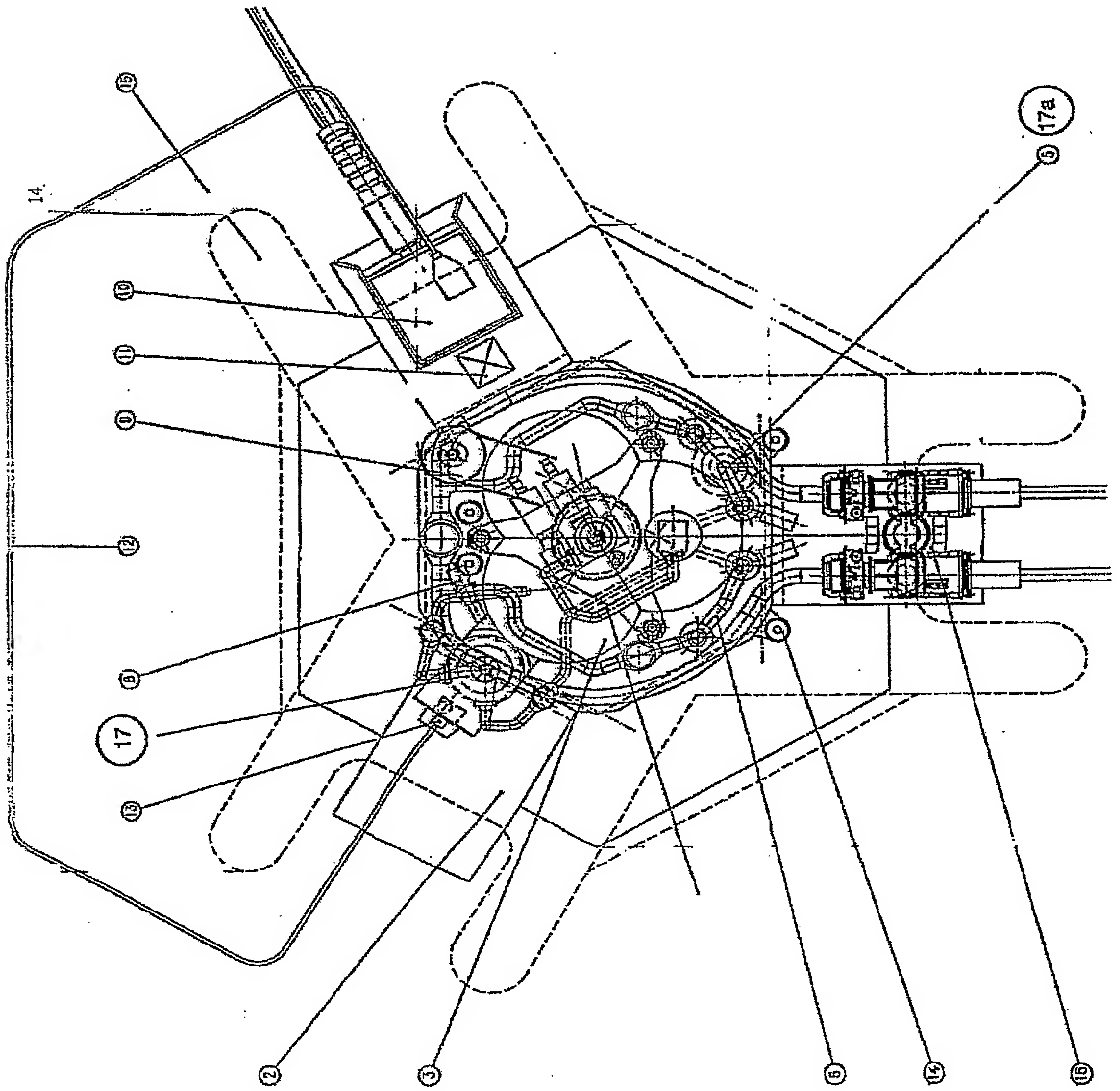


Fig. 5

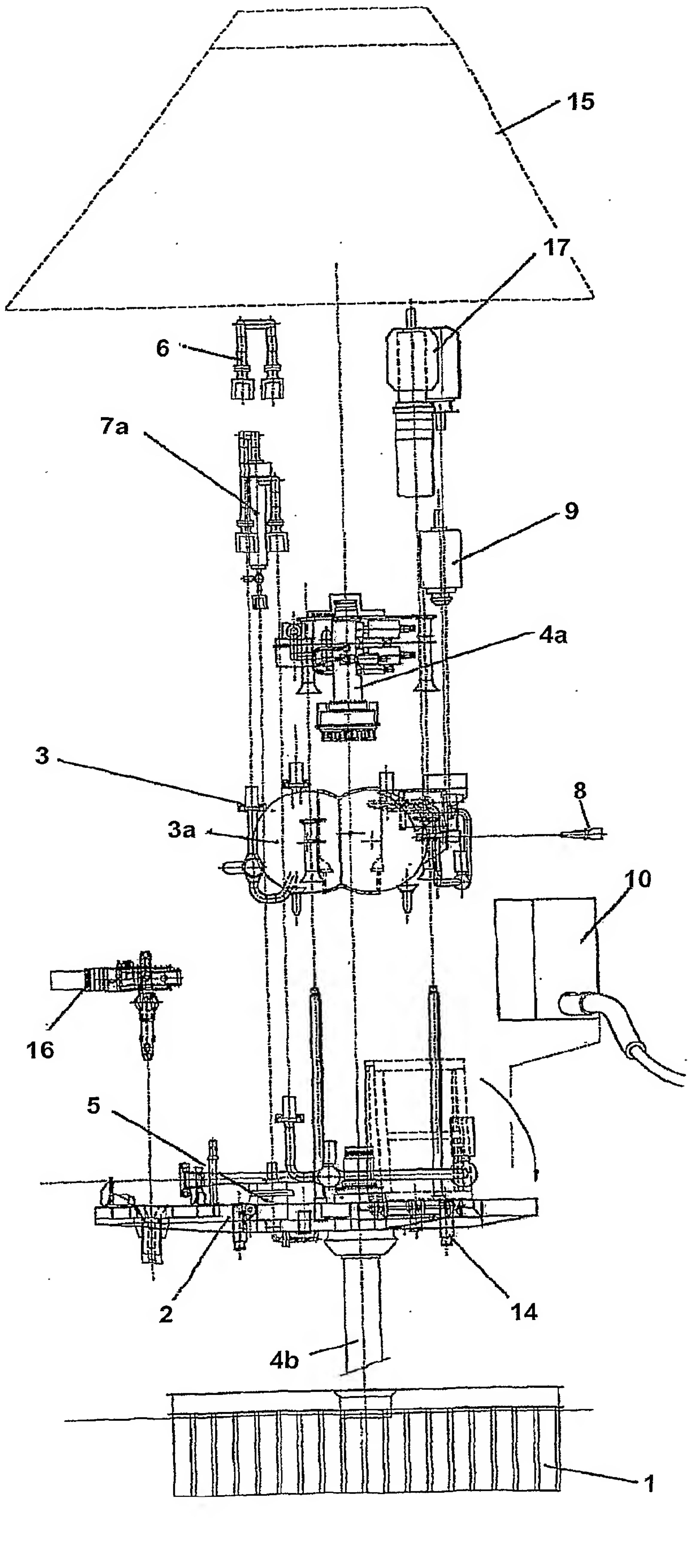



Fig. 6

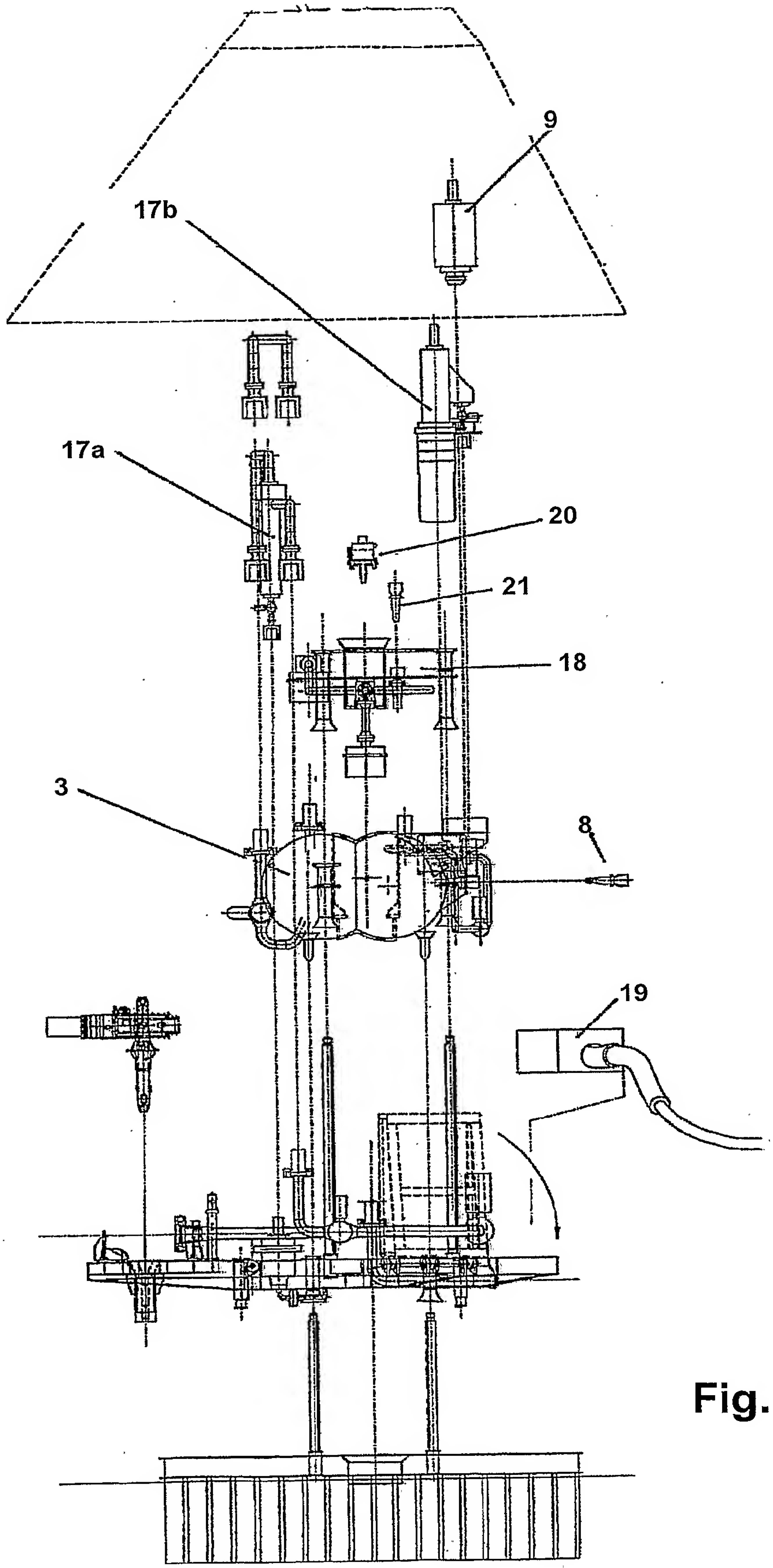



Fig. 7

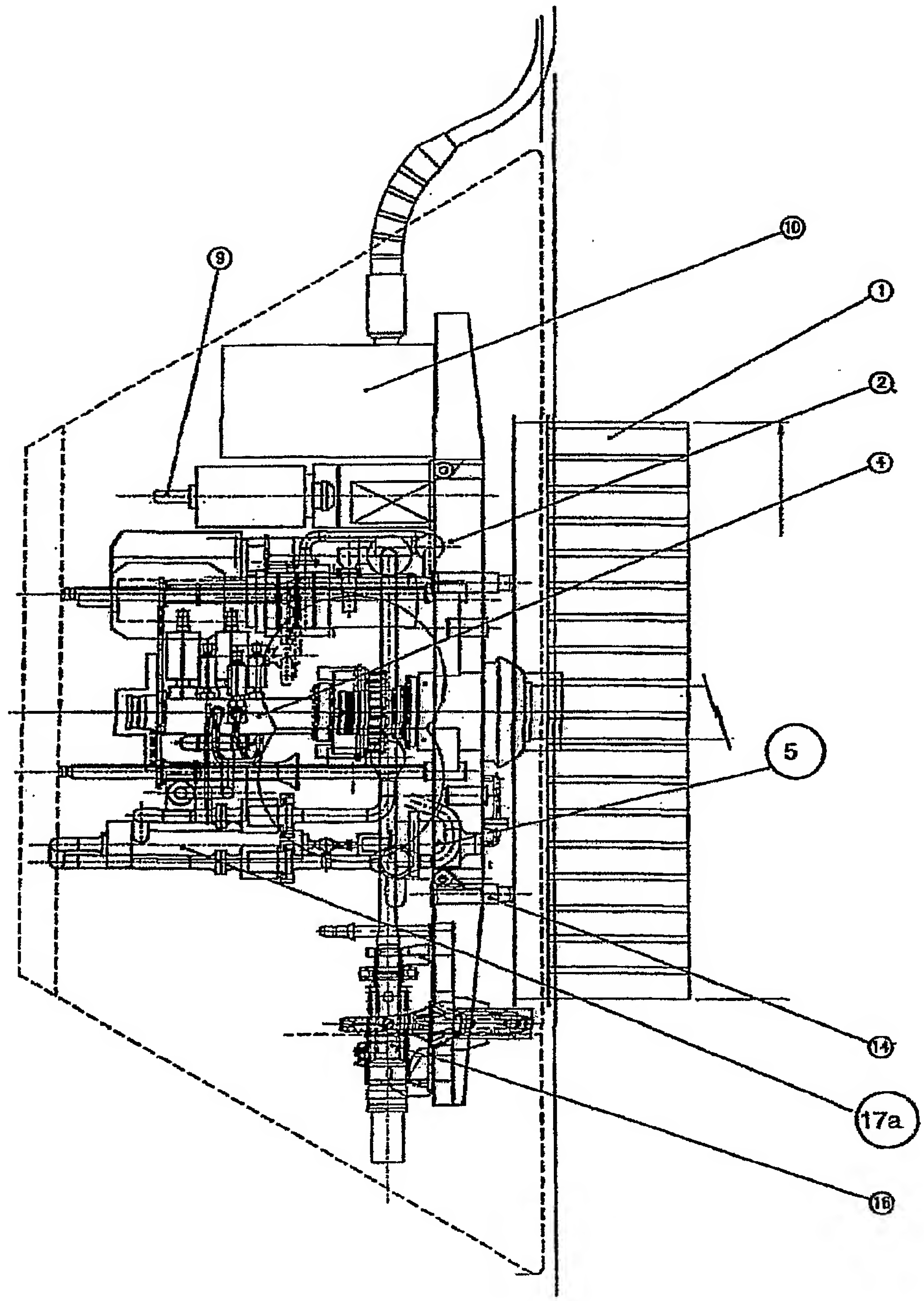



Fig. 8

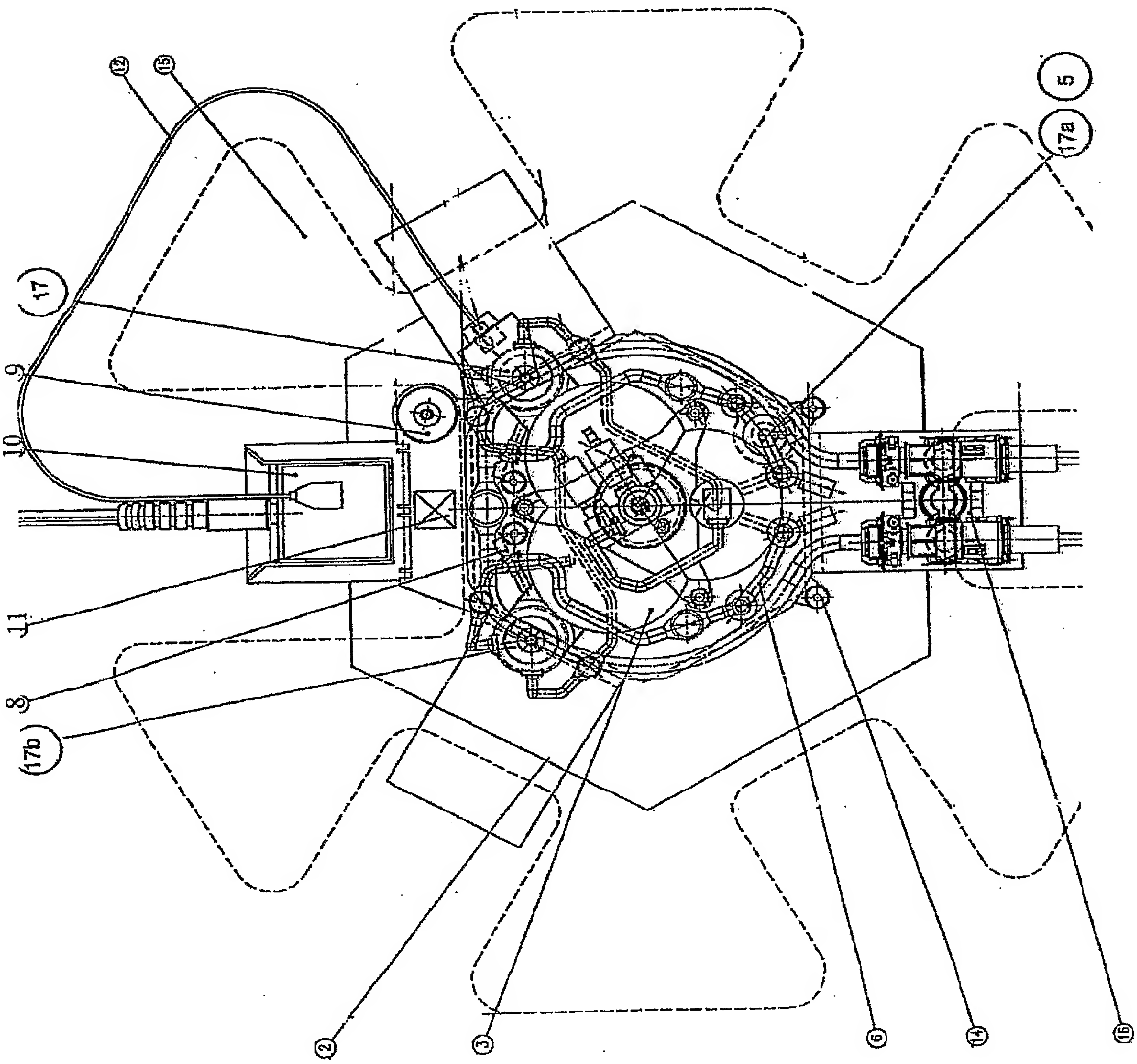



Fig. 9

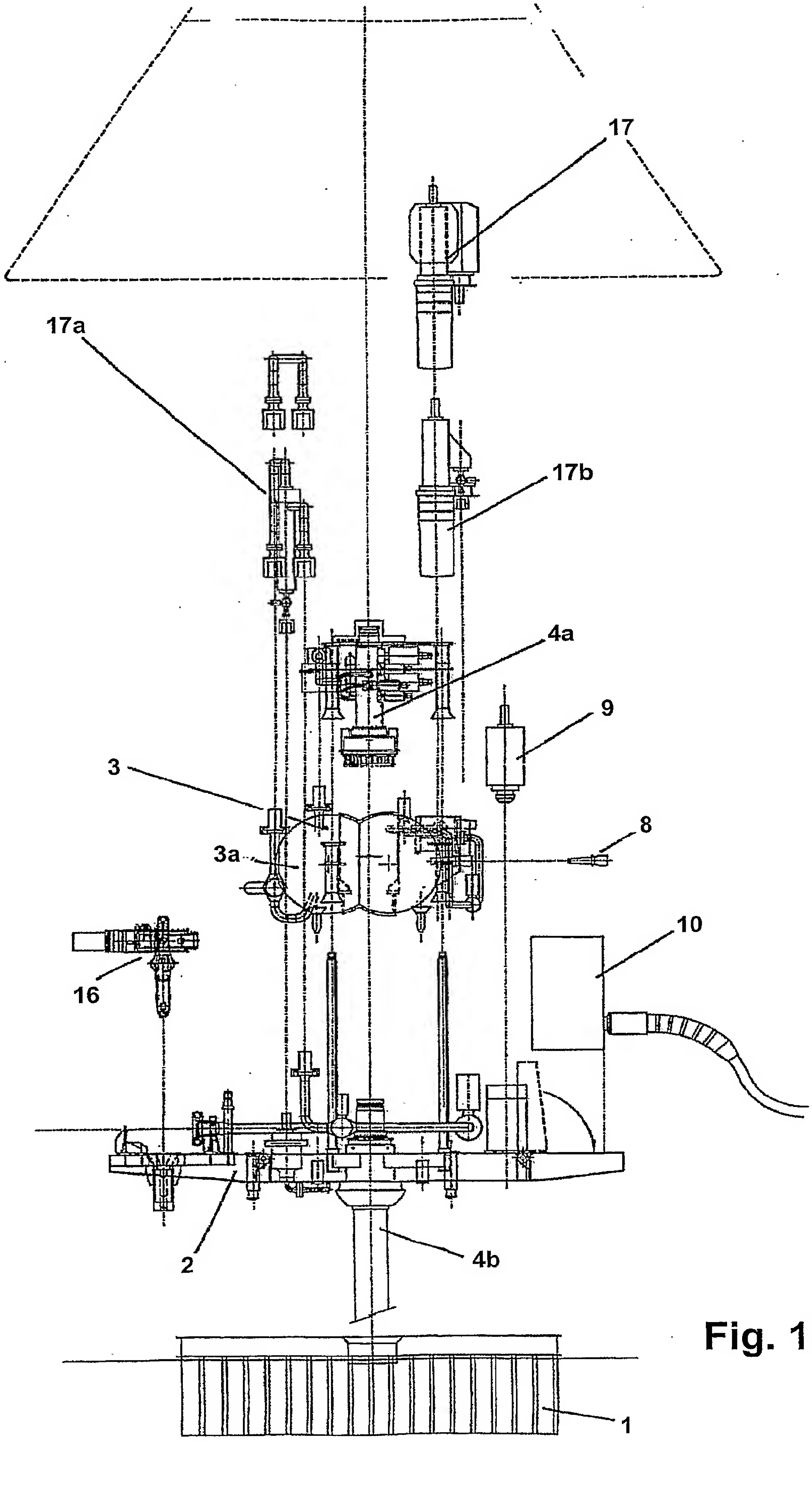



Fig. 10

Fig. 11

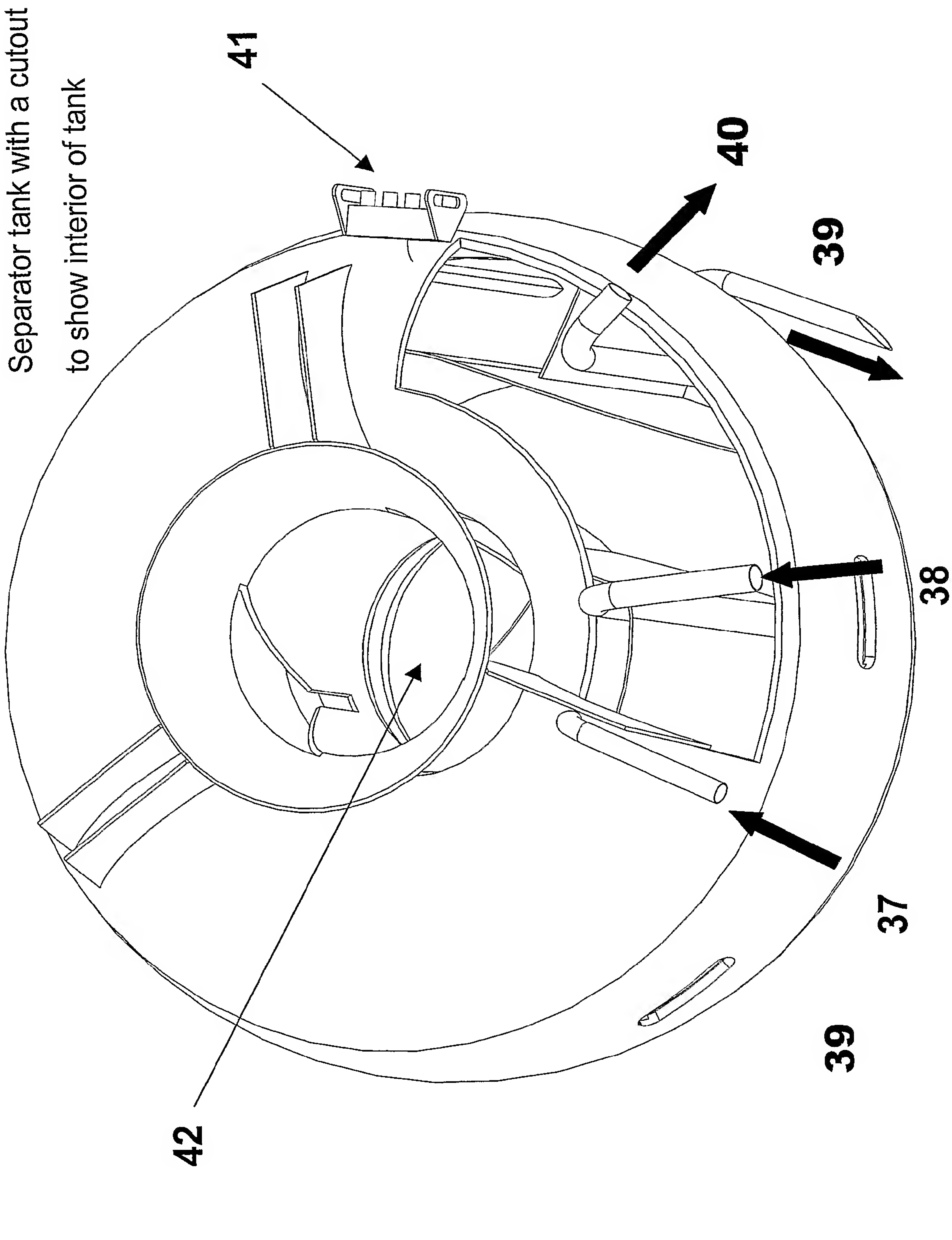
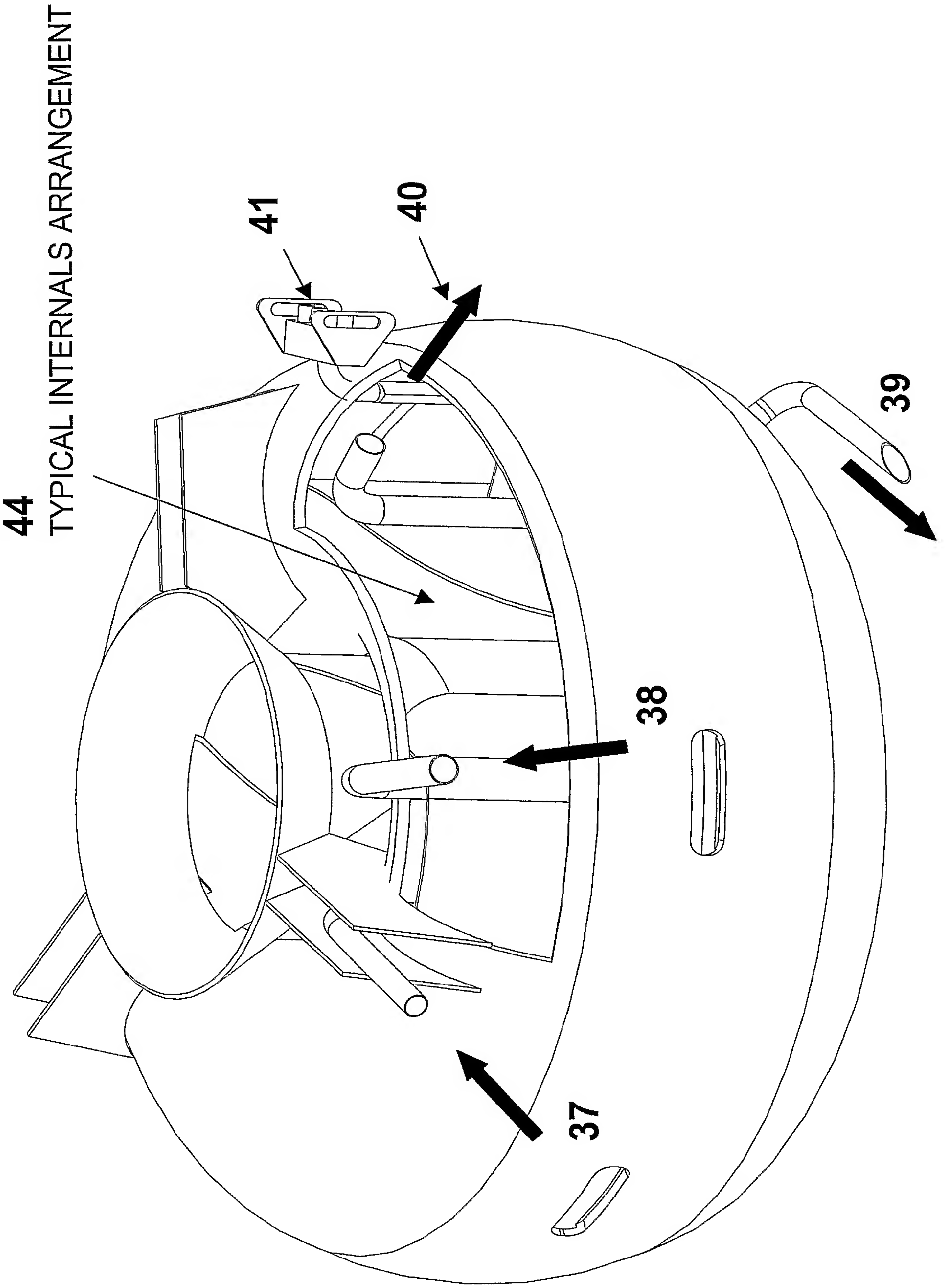

Separator tank with a cutout
to show interior of tank
41
40
39
38
37
39
42

Fig. 12



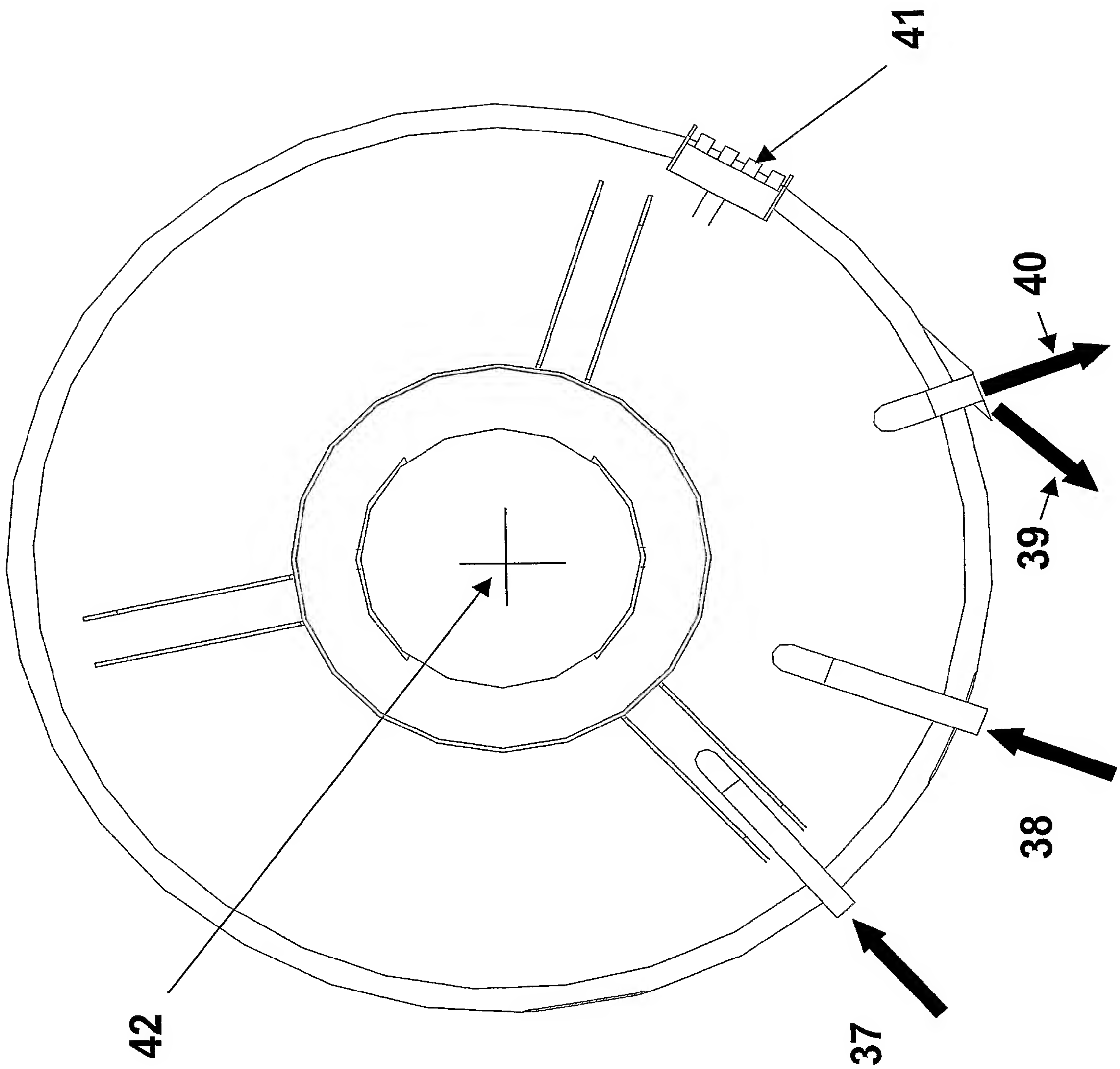



Fig. 13

Fig. 14

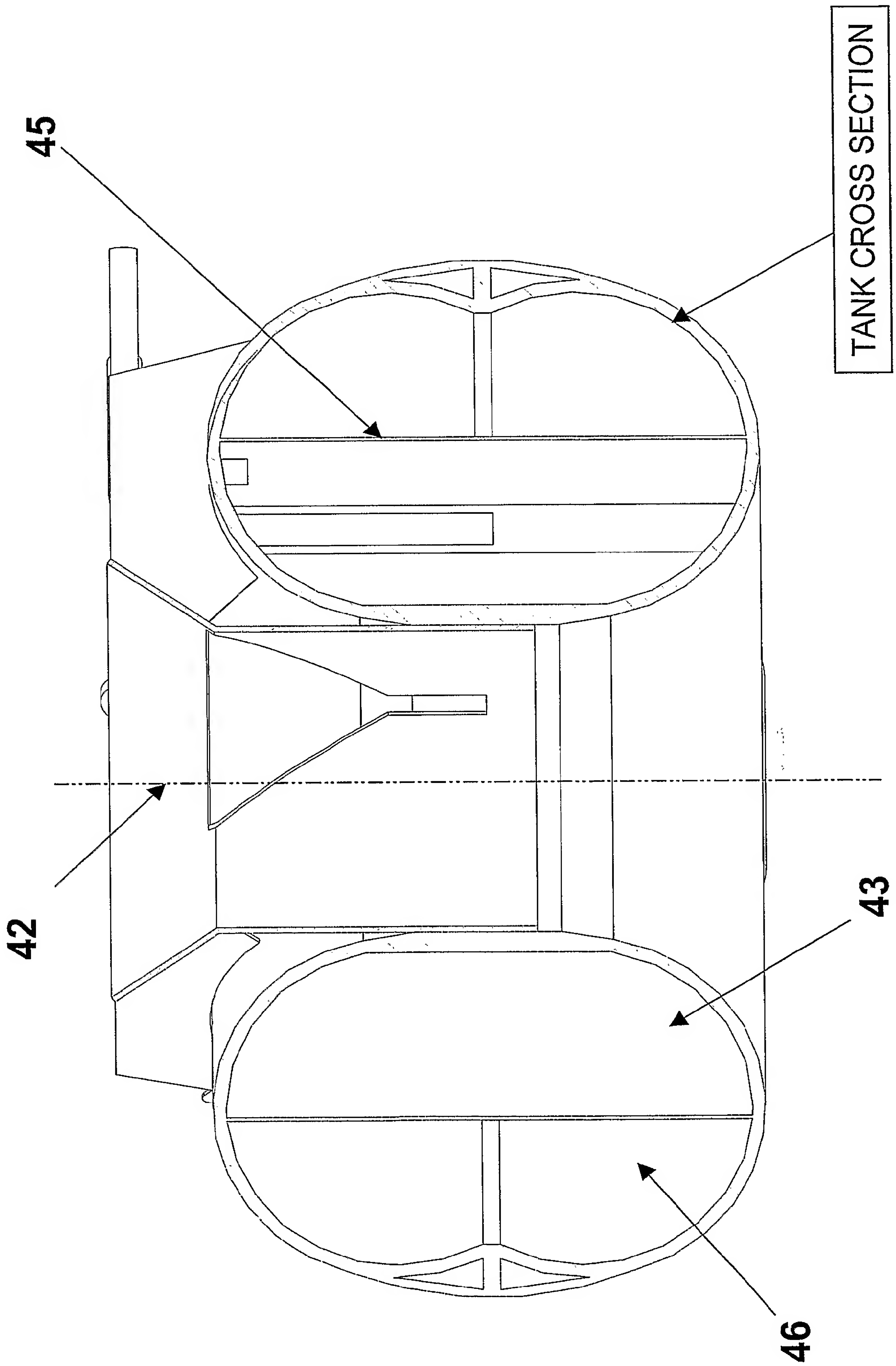
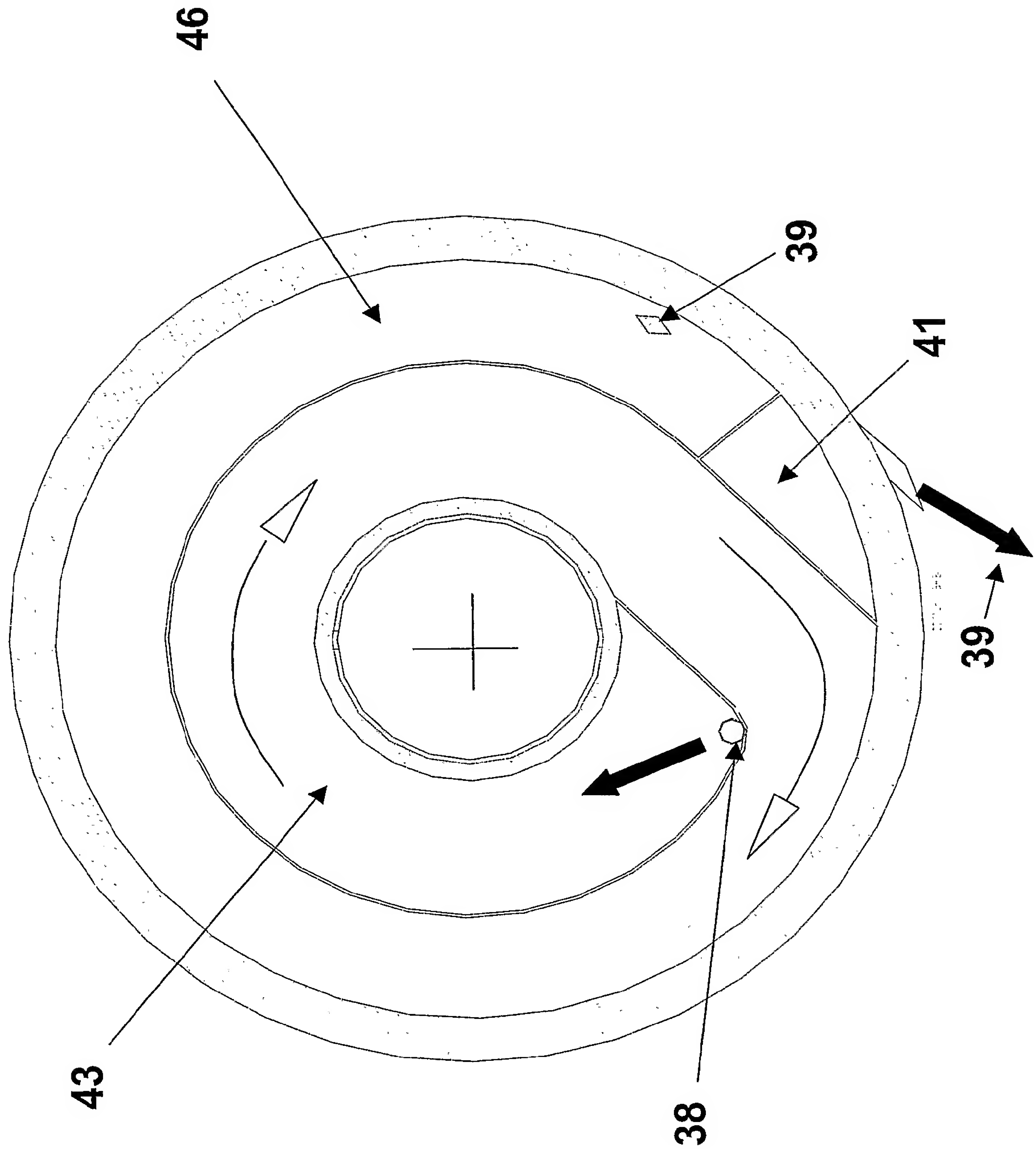


Fig. 15



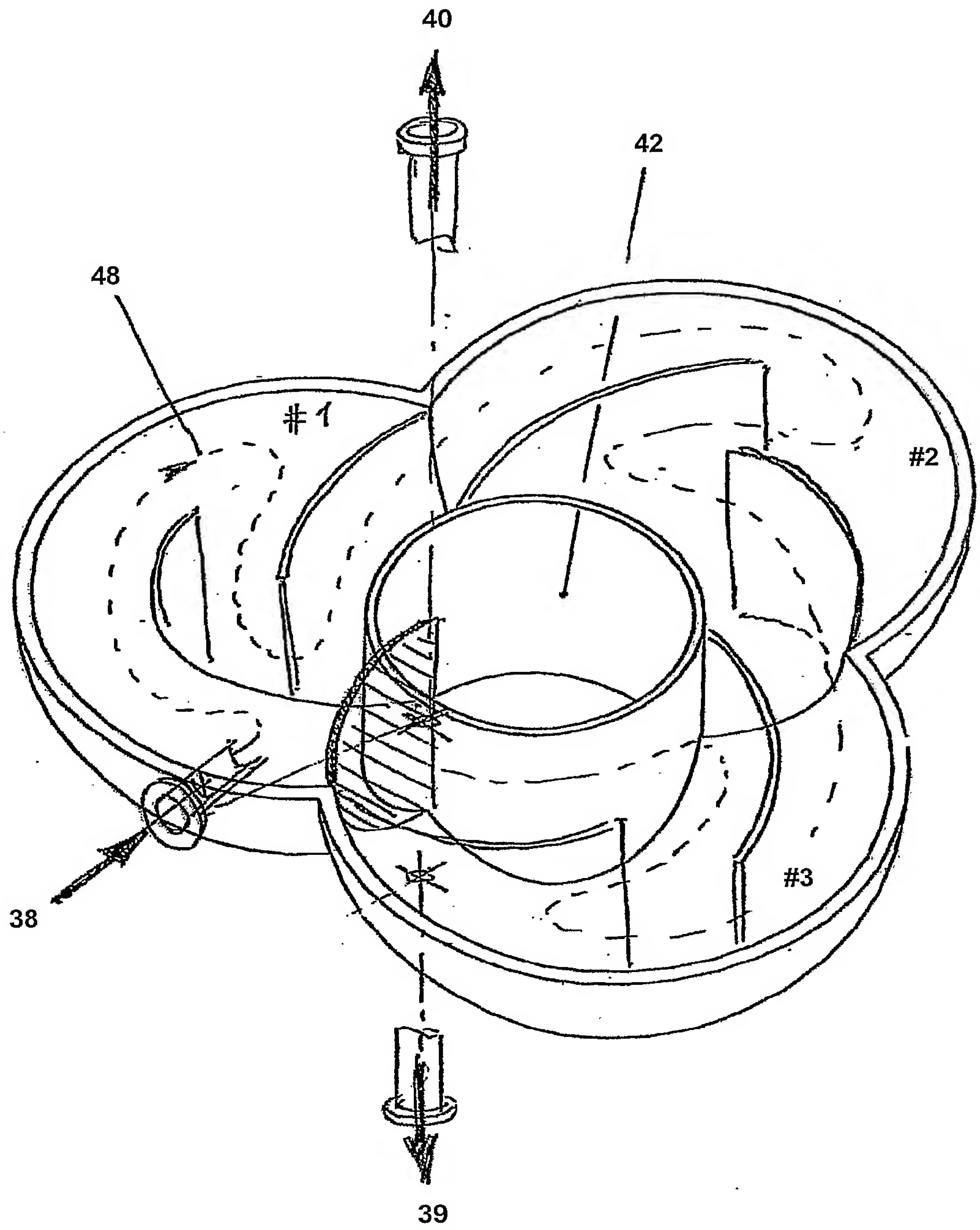



Fig. 16

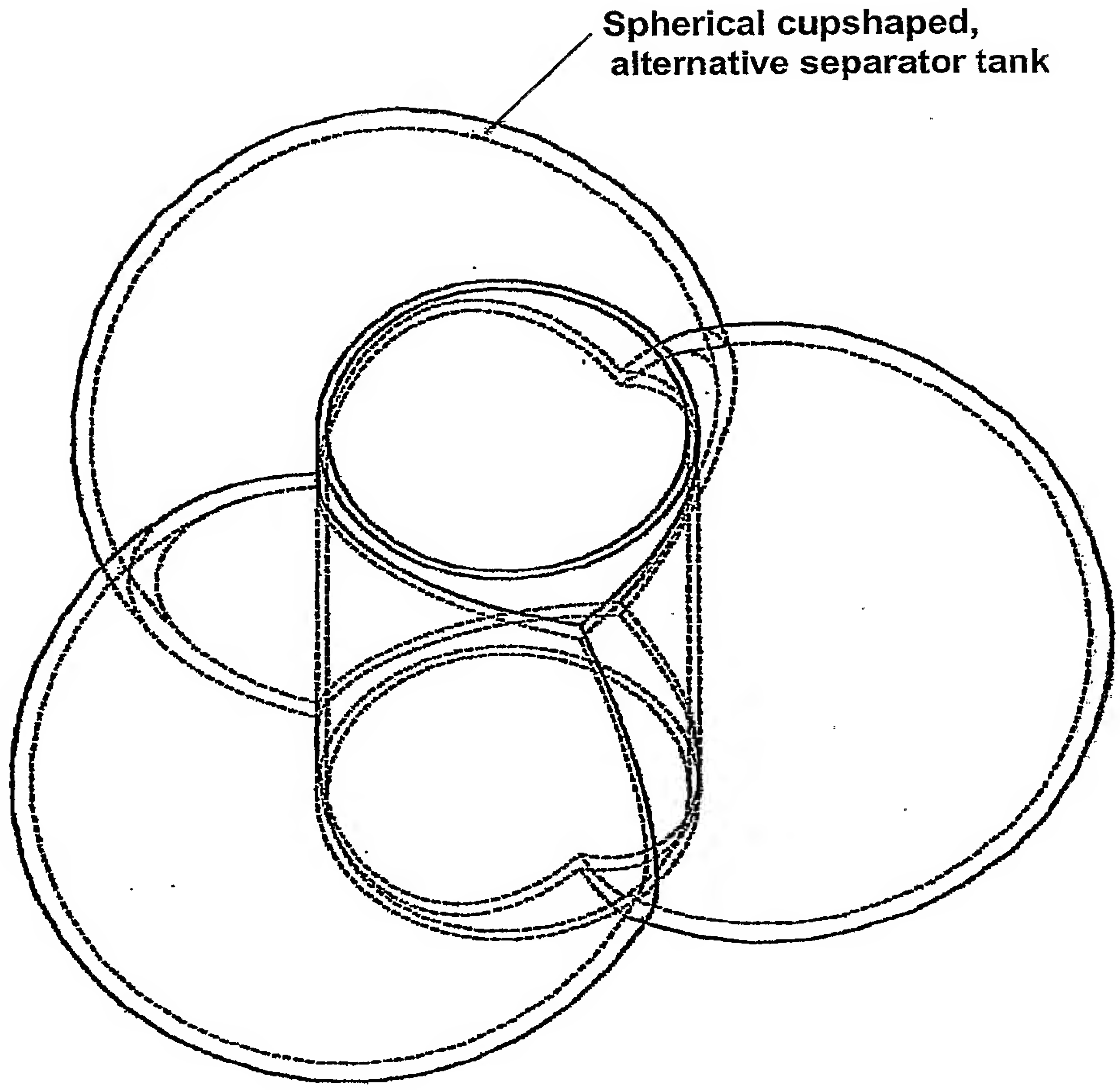
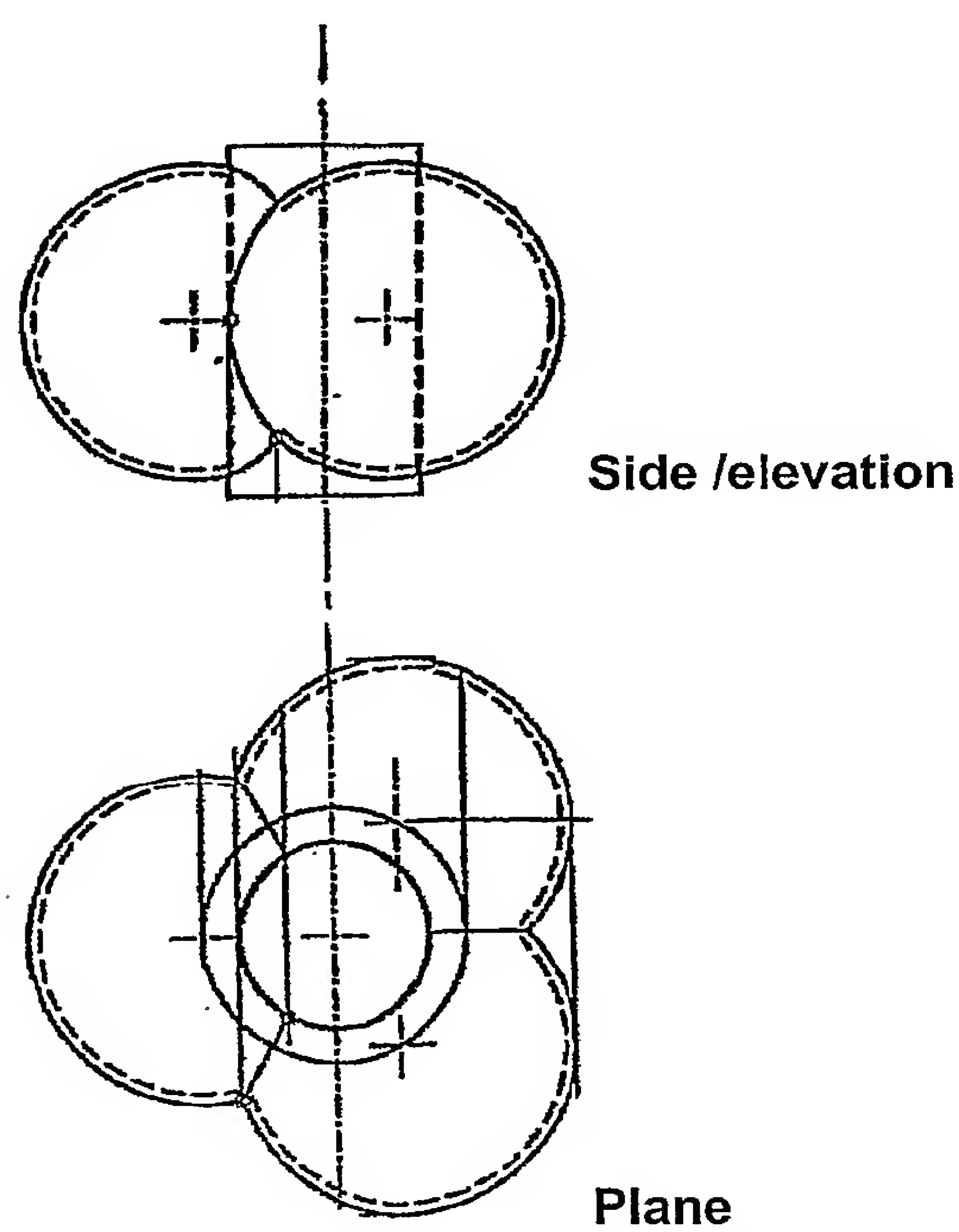

Spherical cupshaped,
alternative separator tank

Fig. 17


Side /elevation
Plane

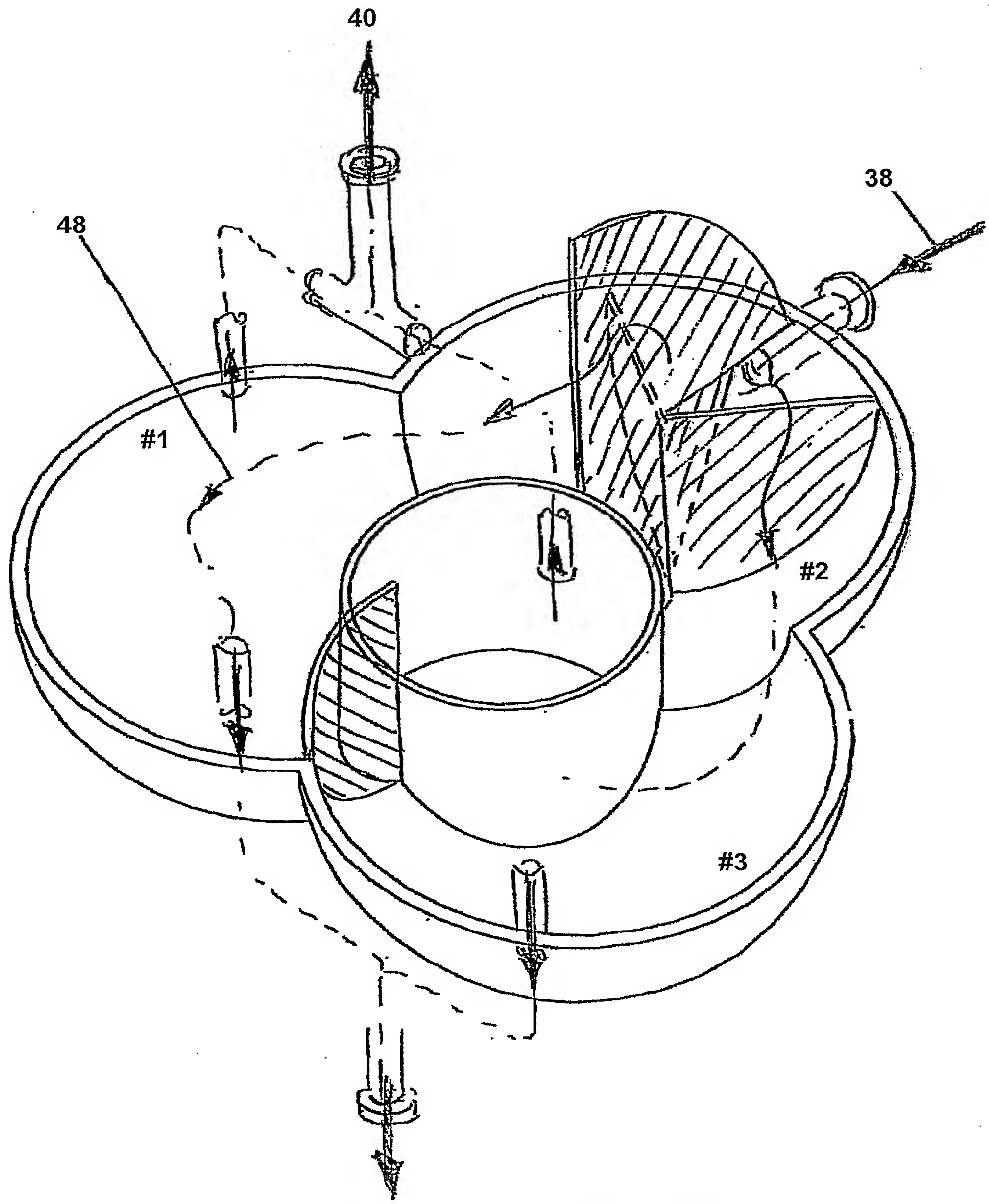



Fig. 18

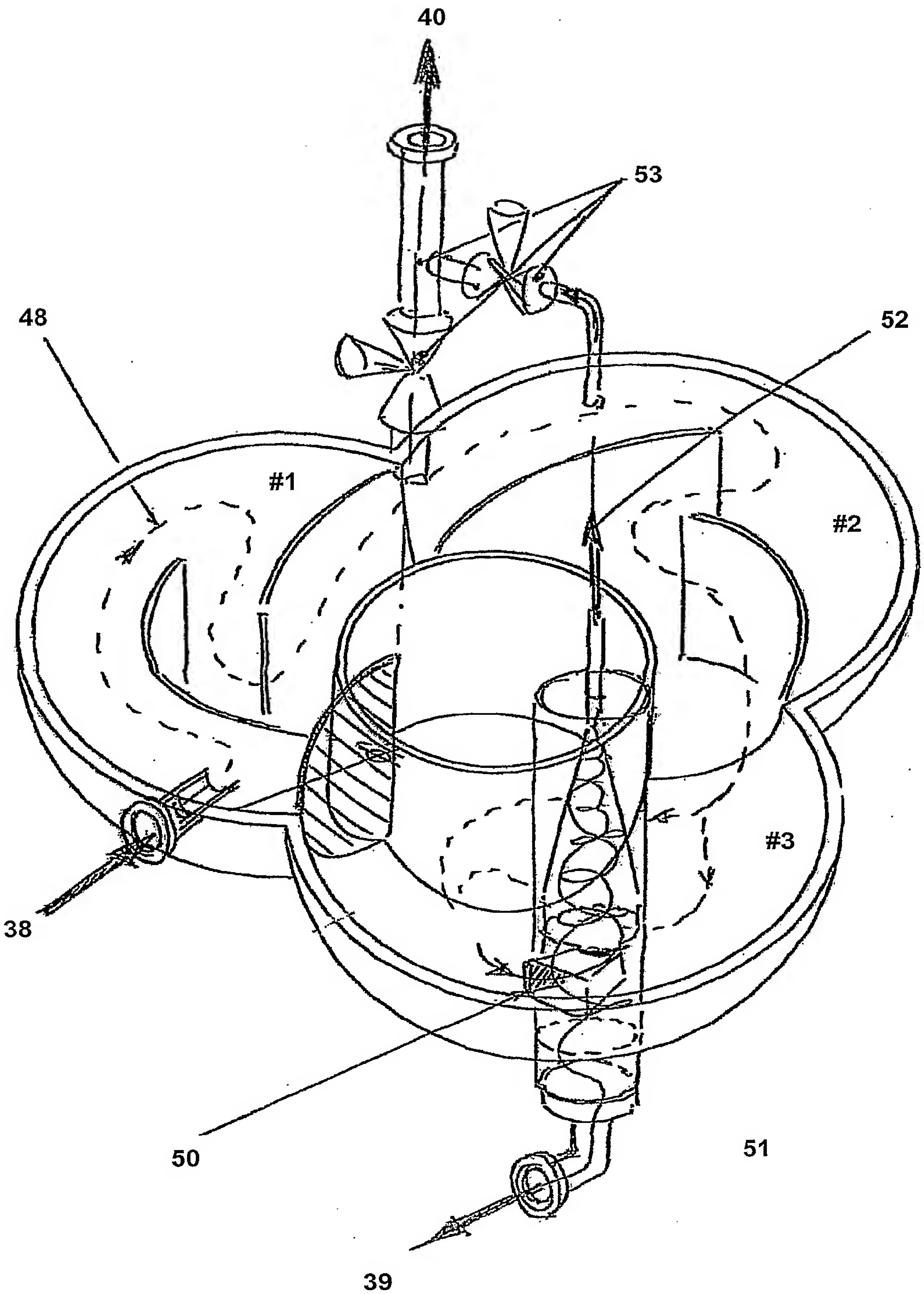



Fig. 19

Fig. 20

Wellhead Unit -
Water Injection

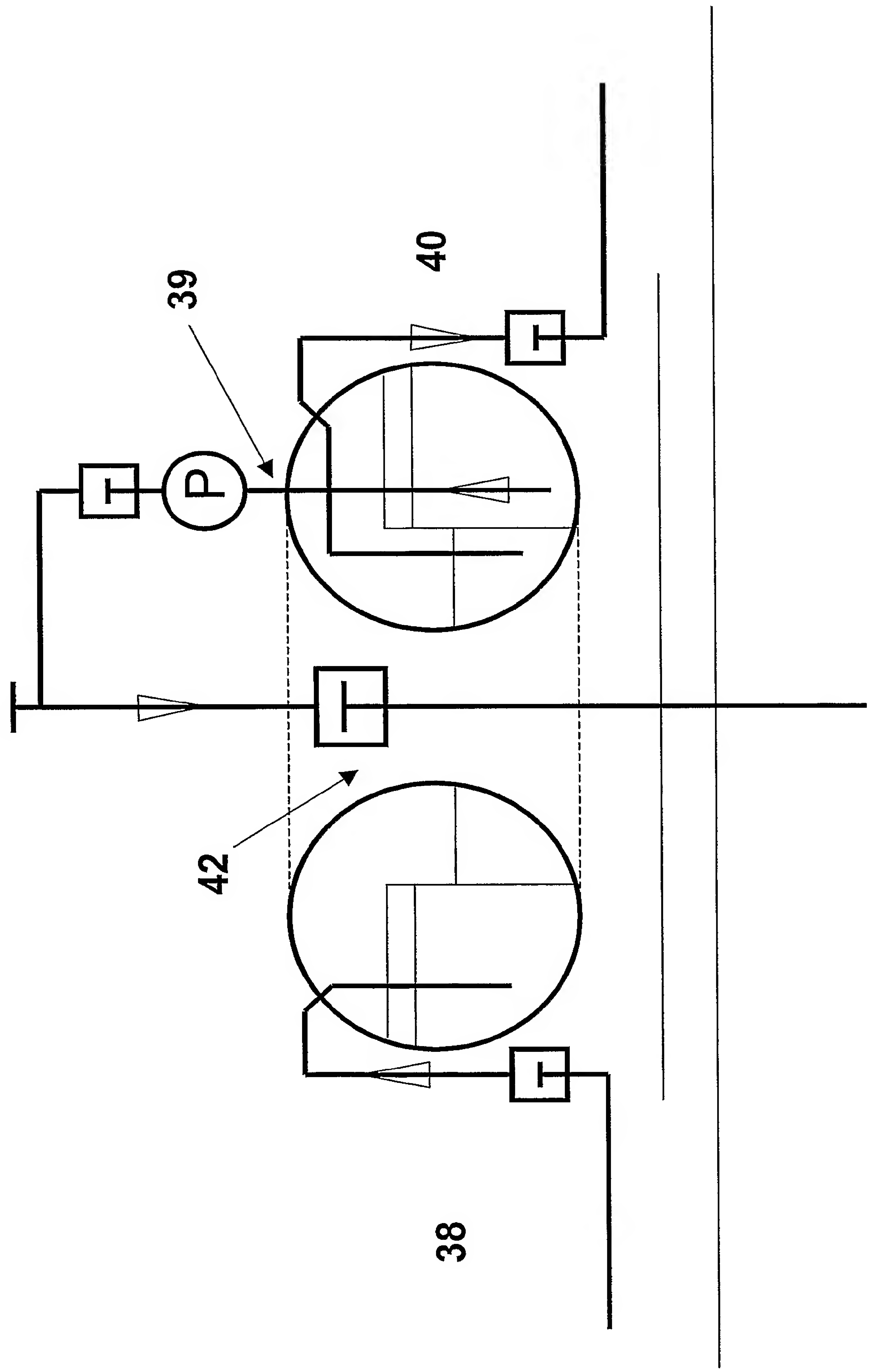
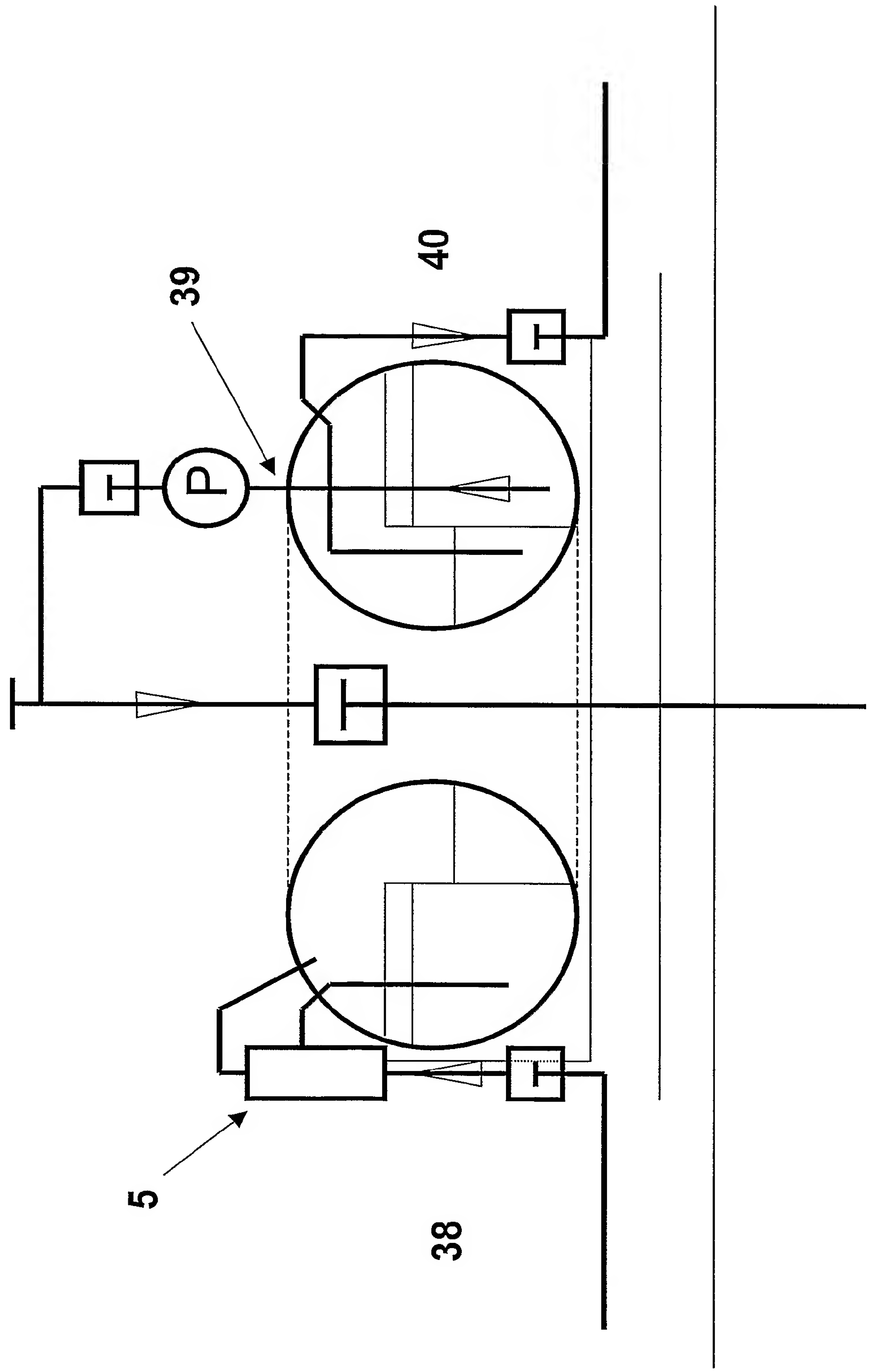


Fig. 21

Wellhead Unit -
Fluid-Gas Cyclone /
Water Injection



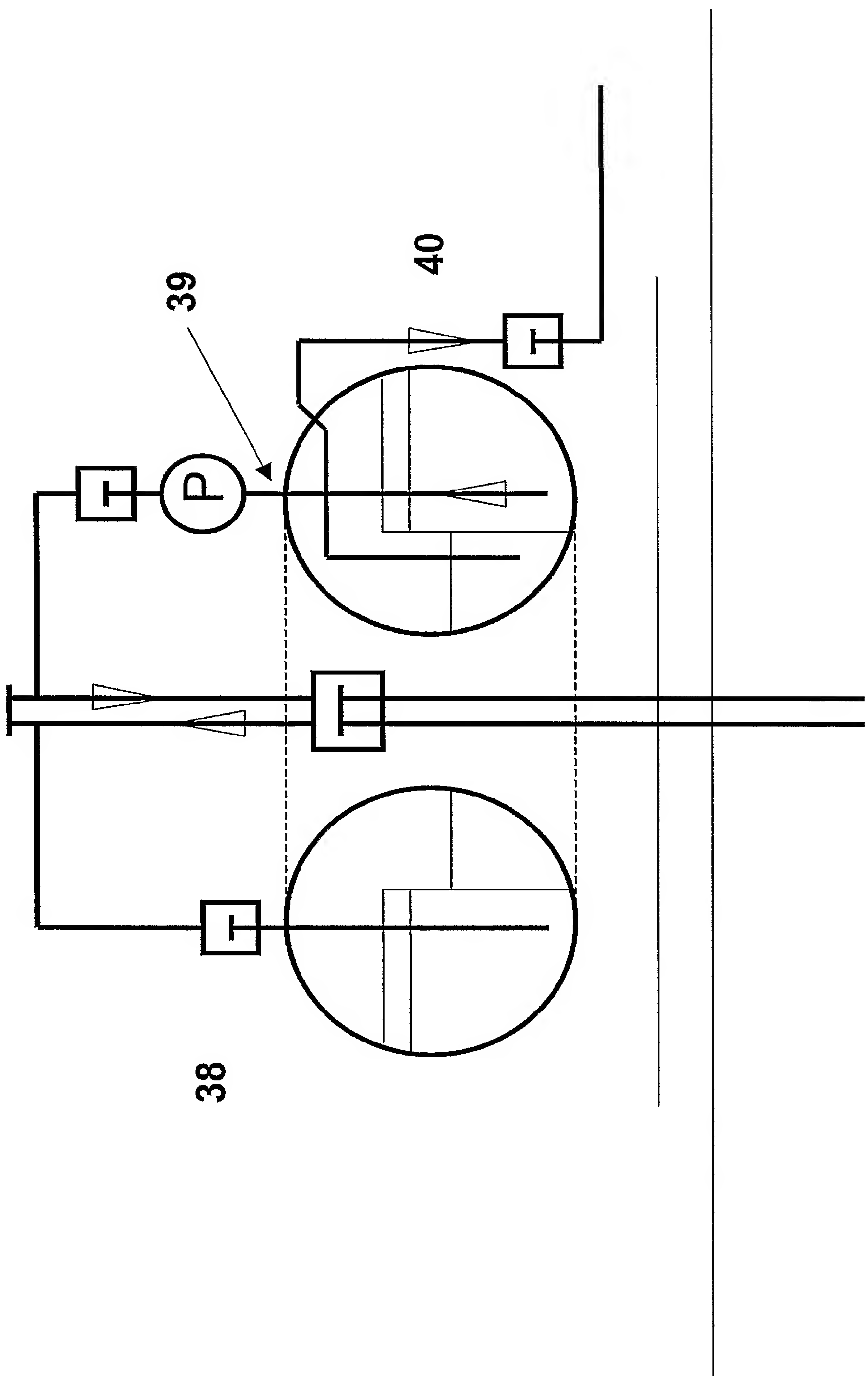



Fig. 22

Wellhead Unit -
Prod. And W. Inj.
Splitter Completion

Compact Unit -
Pump & Separator

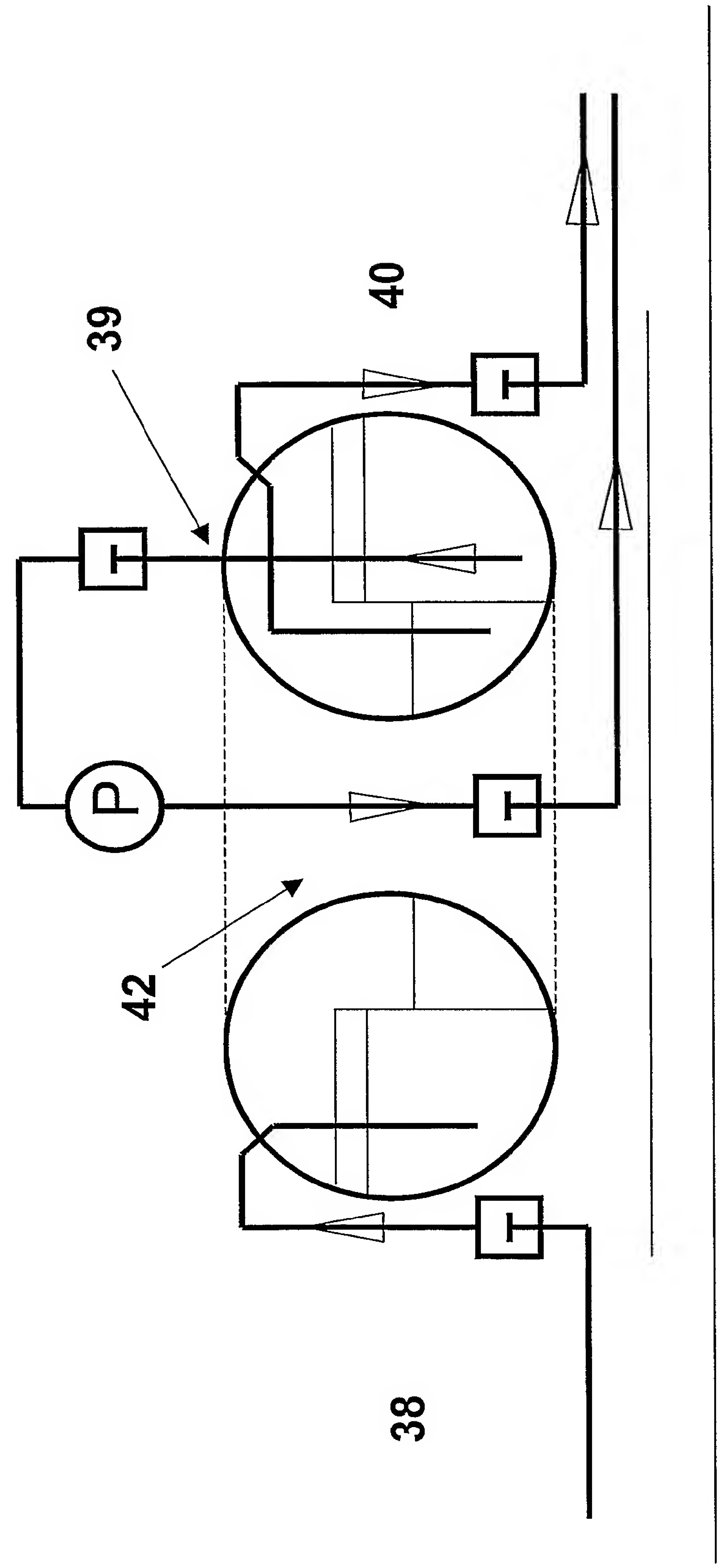
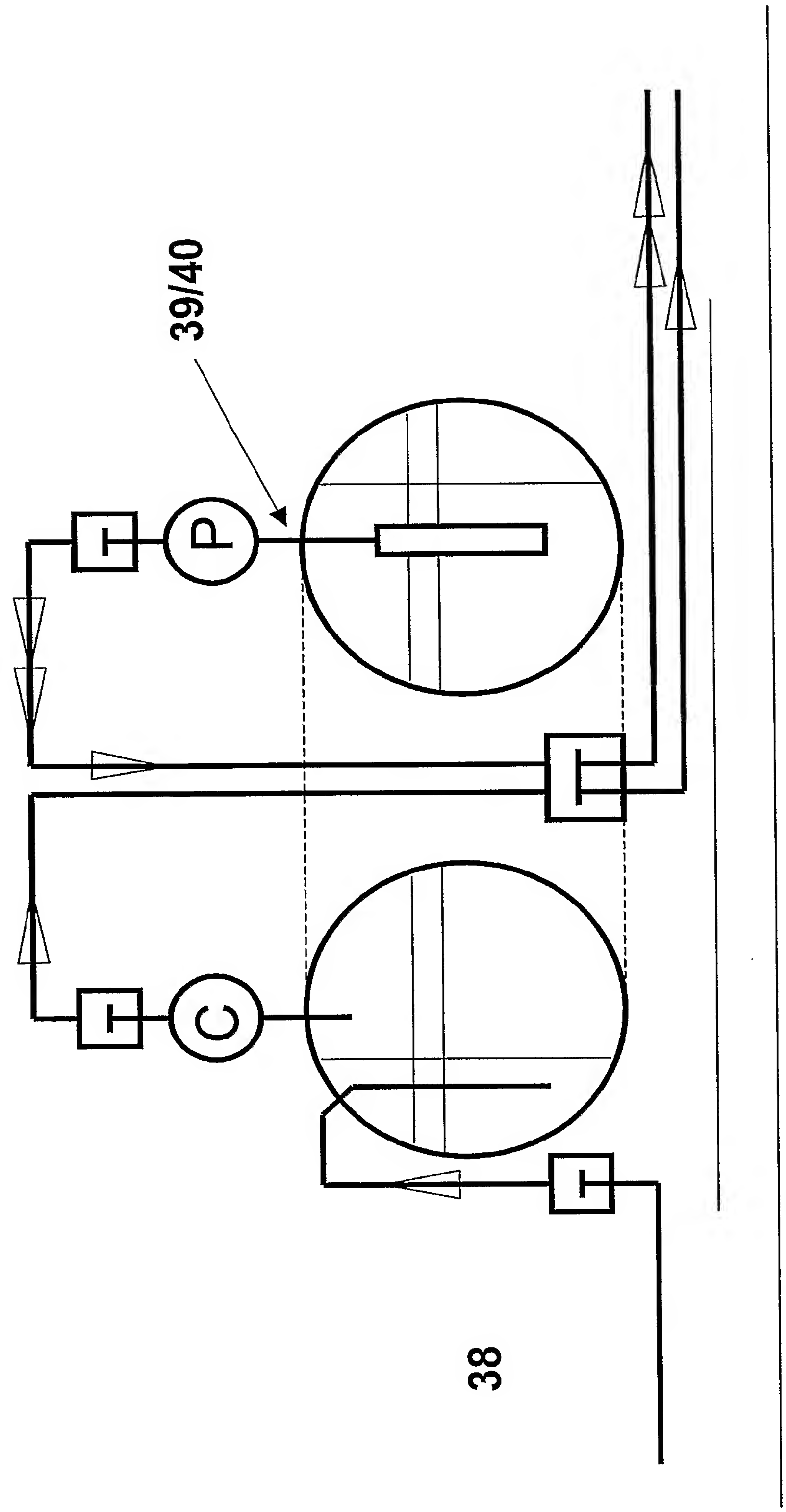



*Fig. 23*

Fig. 24

Compact Unit -
Two Phase
Pressure Boosting



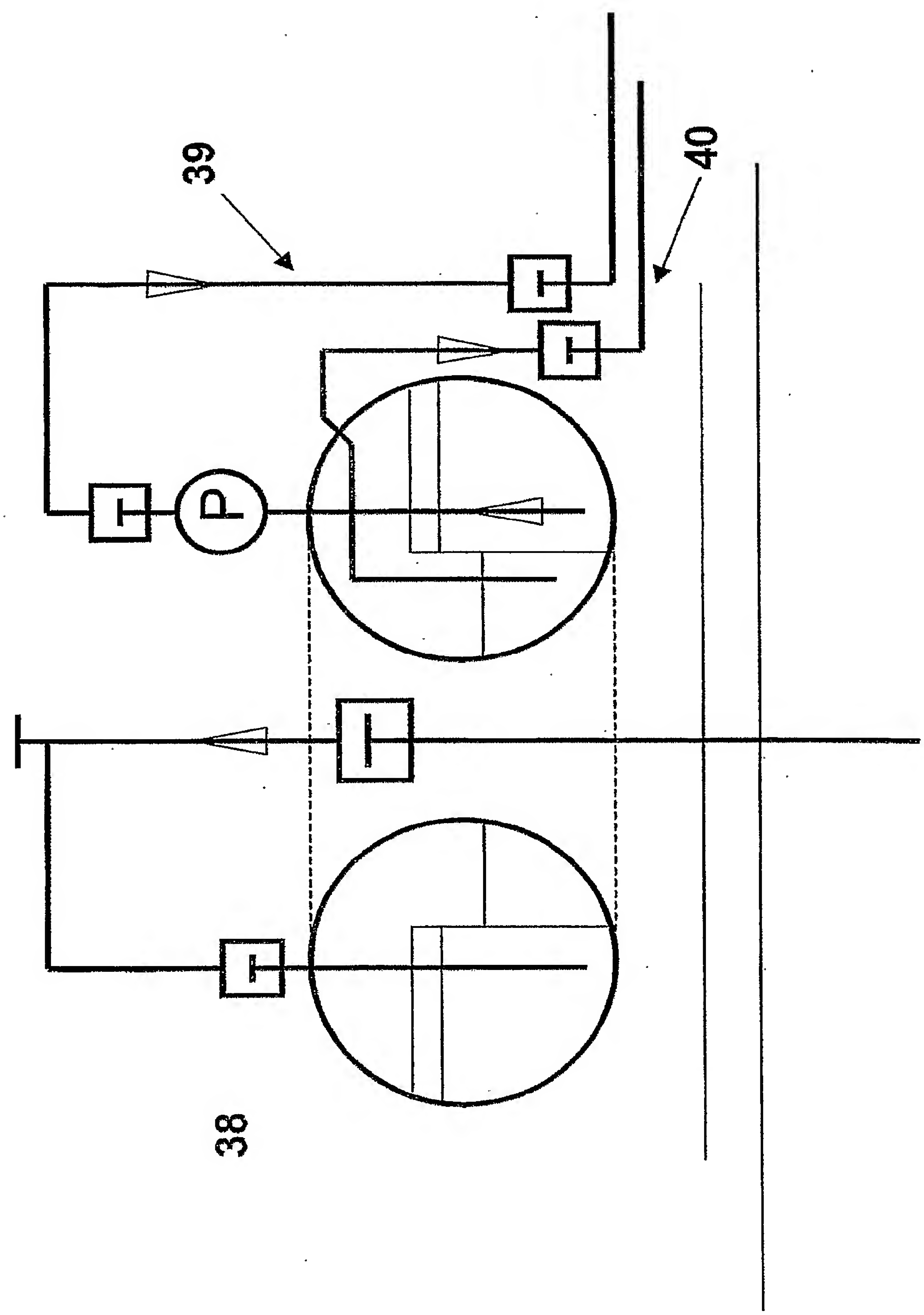
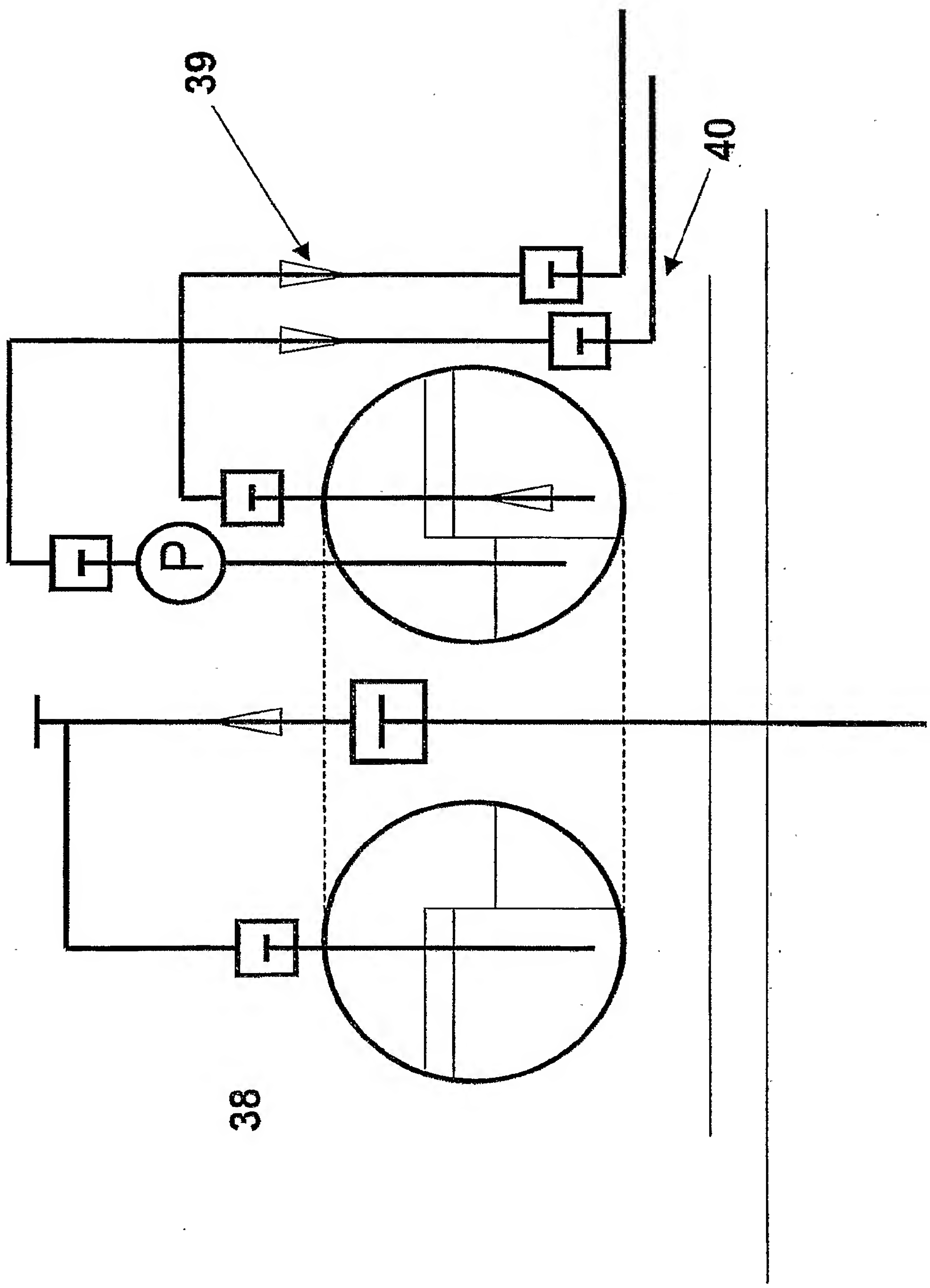



Fig. 25a

Fig. 25b



# INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO 03/00070

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: E21B 43/36
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: E21B, B01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | US 3543846 A (M.W. SMITH ET AL), 1 December 1970 (01.12.70), column 3 - column 5, figures 2,6,7 | 1,2,5,10,12, 14,22 |
| Y | | 3-4,6-9,11 |
| | -- | |
| Y | US 4438817 A (R.L. POKLADNIK ET AL), 27 March 1984 (27.03.84), the whole document | 3,4 |
| | -- | |
| Y | WO 9935370 A1 (KVAERNER OILFIELD PRODUCTS A.S), 15 July 1999 (15.07.99), the whole document | 6-8 |
| | -- | |

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 15 May 2003 | 16 -05- 2003 |
| Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86 | Authorized officer Christer Bäcknert / MRo Telephone No. +46 8 782 25 00 |

## INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO 03/00070

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| Y | GB 2133446 A (TREASURE OFFSHORE PRODUCTION SYSTEMS LIMITED), 24 July 1984 (24.07.84), the whole document | 9,11 |
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| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
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| | | NL 6905852 A | 20/05/70 |
| US 4438817 A | 27/03/84 | GB 2127465 A,B | 11/04/84 |
| | | GB 8323474 D | 00/00/00 |
| WO 9935370 A1 | 15/07/99 | AU 1789599 A | 26/07/99 |
| | | NO 306311 B | 18/10/99 |
| | | NO 980066 A | 07/07/99 |
| GB 2133446 A | 24/07/84 | NONE | |